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COTS SOFTWARE DECISION SUPPORT MODELS FOR USPACOM'S THEATER ENGAGEMENT PLAN (TEP)

by

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As part of the process of achieving national security objectives, the mission of United States Pacific Command (USPACOM) is to enhance security and promote peaceful development in the Asia region by deterring aggression, responding to crisies and fighting to win. USPACOM's Theater Engagement Plan (TEP) contributes to the accomplishment of this mission by planning, coordinating, and implementing peacetime military activities to shape the region's security environment. USPACOM, J56 (Future Plans and Operations, Engagement) has a requirement to assess the effectiveness of engagement activities proposed, planned and conducted within its Area Of Responsibility. USPACOM's goals and objectives for the engagement process have been formally defined, but no process exists to link engagement activities to goals and objectives. Consequently, there is no way to comparatively assess the value of one engagement activity versus another. This research focuses on the basics of Multi-Attribute Utility Theory (MAUT) and Analytical Hierarchy Process (AHP) techniques for alternative selection following a literature review, which addresses some of the issues in decision support, traditional modeling techniques, and some of the traditional methodologies for quantifying subjective judgments. Additionally, this research illustrates the usefulness of currently available COTS decision support software in assisting the decision-maker in this endeavor.

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COTS SOFTWARE DECISION SUPPORT MODELS FOR USPACOM'S THEATER ENGAGEMENT PLAN (TEP)

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requirements for the degree of

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ABSTRACT

As part of the process of achieving national security objectives, the mission of United States Pacific Command (USPACOM) is to enhance security and promote peaceful development in the Asia region by deterring aggression, responding to crisies and fighting to win. USPACOM's Theater Engagement Plan (TEP) contributes to the accomplishment of this mission by planning, coordinating, and implementing peacetime military activities to shape the region's security environment. USPACOM, J56 (Future Plans and Operations, Engagement) has a requirement to assess the effectiveness of engagement activities proposed, planned and conducted within its Area Of Responsibility. USPACOM's goals and objectives for the engagement process have been formally defined, but no process exists to link engagement activities to goals and objectives. Consequently, there is no way to comparatively assess the value of one engagement activity versus another. This research focuses on the basics of Multi-Attribute Utility Theory (MAUT) and Analytical Hierarchy Process (AHP) techniques for alternative selection following a literature review, which addresses some of the issues in decision support, traditional modeling techniques, and some of the traditional methodologies for quantifying subjective judgments. Additionally, this research illustrates the usefulness of currently available COTS decision support software in assisting the decision-maker in this endeavor.

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I. INTRODUCTION

A. BACKGROUND

The mission of United States Pacific Command (USPACOM) is to enhance security and promote peaceful development in the Asia-Pacific region by deterring aggression, responding to crisies and fighting to win in support of our national security objectives. The U. S. Commission on National Security/21st Century, co-chaired by Senators Gary Hart and Warren Rudman (2000), recently stated that among other issues:

> It is a critical national interest of the United States that no hostile power establish itself on U.S. borders, or in control of critical land, air, and sea lines of communication, or--in today's new world--in control of access to outer space or cyberspace. It is a critical national interest of the United States that no hostile hegemon arise in any of the globe's major regions, nor a hostile global peer rival or a hostile coalition comparable to a peer rival…

Additionally, the commission stated that the security of allies and friends is a critical national interest of the United States and that one of the key objectives is to assist in the economic and political integration of China, India and Russia into the mainstream of the international community (Hart and Rudman, 2000). USPACOM's Theater Engagement Plan (TEP) contributes to the accomplishment of this mission by planning, coordinating, and implementing peacetime military activities to shape the region's security environment.

The design of USPACOM's TEP is to identify realistic endstates that support the prioritized regional objectives for the Area of Responsibility (AOR), plan those activities that support accomplishment of the approved endstates and coordinate the components' efforts to shape the Asia-Pacific regional security environment. Engagement planning

helps foster the development of security communities by focusing on three themes: goodwill, access, and competent coalition partners.

USPACOM's engagement strategy for the AOR is to enhance basic goodwill relations, improve access for U.S. forces and develop competent coalition partners in order to facilitate the development of security communities, which in-turn, will enhance security and promote peaceful development in the Asia-Pacific region.

B. STATEMENT OF THE PROBLEM

The current TEP's guidance and assistance policy focuses on the engagement of Security Communities within its theater. These Security Communities are defined as groups of nations that don't plan or want to fight each other, that cooperate in the peaceful resolution of disputes, and that work together on other common issues. These groups of nations are considered neither a defense community nor a security alliance.

As previously stated, USPACOM's engagement strategy, as it concerns these security communities, focuses on three entities: goodwill relations, access (training and contingencies), and regional readiness. Regional readiness is the mechanism for developing competent coalition partners and is mainly concerned with interoperability issues such as tactics, techniques and procedures and foreign military sales. Regional readiness is also concerned with combined operations involving humanitarian issues.

The engagement strategy of each individual country focuses on four areas of engagement. USPACOM is interested in utilizing a coordinated focus approach in order to expand current engagement activities. USPACOM is also interested in continuing existing relationships to foster current and future engagement activities. Additionally,

USPACOM is interested in increasing the potential efficiencies in order to tailor current and future engagement activities to achieve specific objectives. Finally, USPACOM is interested in developing a way to effectively interact with countries that possess engagement restrictions. These engagement restrictions may exist due to various political, military and/or economic considerations.

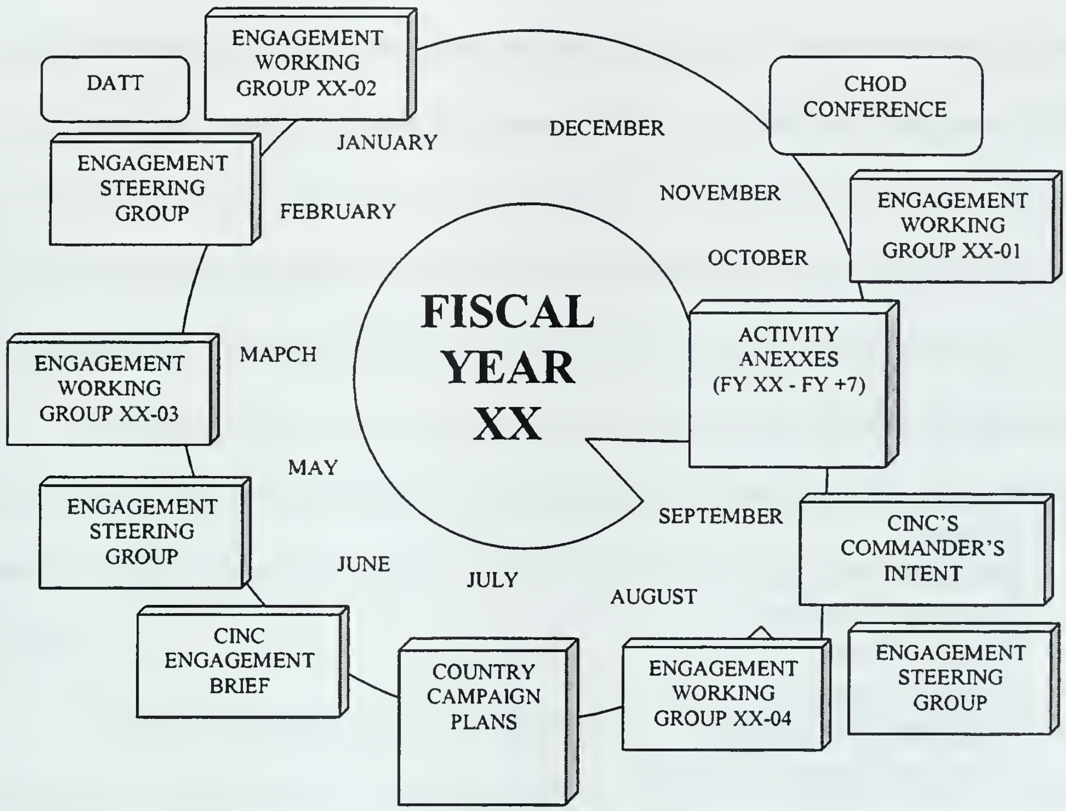

Figure 1.1 - USPACOM Engagement Planning Cycle.

The endstates and objectives of the theater engagement activities are put forth by the USPACOM Commander-In-Chief (CINC) and are not consider negotiable. However, the ends and means of achieving these objectives are somewhat negotiable between the

joint staff members and USPACOM's subordinate and supporting agencies.

The USPACOM engagement planning cycle is a 12-month cycle that involves inputs from numerous and various internal and external sources. As shown in Figure 1.1, the Engagement Working Groups (EWGs), consisting of country representatives, meets four times throughout the year and plan projected engagement activities for forthcoming fiscal years. This planning cycle consists of the coordination, interaction, and decision making of 35 separate internal and external staff and support entities in the pursuit of the USPACOM's engagement goals and objectives and is projected out for seven fiscal years.

The engagement activities employed by USPACOM are categorized by type and consist of 12 separate areas, which fall under eight major TEP categories. These major TEP categories are as follows:

- Operational Activities
- Exercises
- Combined Training
- Combined Education
- Military Contacts
- Security Assistance
- Humanitarian Assistance
- Other Engagement Operations

Under these main categories, USPACOM is interested in pursuing 12 types of engagement activities: Counterdrug and Repatriation operations (Operational Activities); Exercises; Training; Education; High Level Visits, Port Visits, Conferences, and Exchanges (Military Contacts); Education and Foreign Military Sales (Security Assistance); Humanitarian Assistance; and Other Engagement Operations. It should be

noted that the quantity, level and type of engagement activity chosen is dependent on the intricacies of the particular country being considered.

USPACOM J56 (Future Plans and Operations, Engagement) has a requirement to assess the effectiveness of engagement activities proposed, planned and conducted within USPACOM's AOR. Although the CINC's goals and objectives for the engagement process have been formally defined, there exists no formal process to link the engagement activities and their effectiveness to the goals and objectives. Consequently, there currently is no way to gauge the impact of the most significant engagement activity or comparatively assess the value of one activity type versus another in the achievement of a particular goal or objective.

C. SCOPE

The aim of this work is to develop a basic understanding of what decision analysis and decision support aides can do for decision-makers, their usefulness, appropriateness, and some of their limitations in the context of engagement activity selection and evaluation.

This thesis will begin with a limited review of decision analysis, decision models, and decision support systems in order to provide a basic foundation for other concepts presented in later sections. This work will also briefly look at the function and utility of different model types that may be useful to decision-makers in the process of decision analysis and alternative selection. Additionally, this thesis will provide a limited review and comparison of the theoretical basis of Multi-Attribute Utility Theory (MAUT) and the Analytical Hierarchy Process (AHP) decision analysis and support methodologies and

how they may be applied to USPACOM's engagement activity selection problem.

The primary focus of this work will provide a limited analysis of the capabilities of Expert Choice™, a Commercial-Off-The-Shelf (COTS) software application, which employs the AHP methodology. The purpose of this analysis will be to determine the usefulness of this application in aiding USPACOM's decision-makers in selecting the most effective theater engagement activities from a list of available alternatives.

II. REVIEW OF DECISION THEORY, MODELS, AND SUPPORT SYSTEMS

A. DECISION THEORY

A good decision usually results from the application of logic, review of all available data and alternatives, and pursuit of a quantitative approach. There are times when a decision, initially thought to be good, obtains unfavorable or unexpected results. Although the results of the decision were unfavorable, the decision is still a good one due to the fact that the decision was made properly. Conversely, poor decisions that fail to apply logic, fail to consider all of the available information, fail to consider all of the alternatives, and fail to apply some quantitative approach can still result in a favorable outcome. However, a decision that produces favorable results through the use of faulty logic and incomplete data and information is still considered a poor decision. The application of some of the basic tenets of decision theory along with the use of some decision support systems will increase the occurrence in which the decision-maker achieves a successful outcome. (Render and Stair, 1997)

Regardless of the type of decision to be made, Render and Stair (1997) believe that decision-making is a six-step process. These six steps are as follows:

1. The problem is clearly defined.
2. All possible alternatives are listed.
3. Possible outcomes are identified.
4. Each combination of alternative and outcome is listed with respect to its expected payoff.
5. Select one of the available decision support theory models.
6. Apply the model, analyze the results and make your decision.

The amount and type of information or knowledge they have about the particular situation usually influences the decision-making of most leaders. In 1960, Dr. Herbert A. Simon provided an early descriptive model of the decision-making process that involved the use of three major sub-processes. These three sub-processes are just as sound today and still very applicable. The sub-processes are as follows:

- Intelligence – The stage where the decision-makers scan their environment for potential problems/opportunities that will require the making and execution of decisions.
- Design – The stage that consists of the generation, development, analysis and feasibility assessment of potential courses of action or alternatives.
- Choice – The stage where one course of action or alternative is selected and eventually implemented. (Young, 1989)

As proof of their validity today, compare them with Young's (1989) statement that

> Decision theory envisions any decision problem as consisting of the elements of:
>
> - Alternative strategies defined as courses of action or a particular combination of "settings" of the variables under the control of the decision-maker.
> - A combination of conditions (particular "settings") of relevant variables which are not controllable by the decision-maker (traditionally called "states of nature" although the conditions could be man-made by persons other than the decision-maker).
> - Interactions between strategy and each state of nature that result in outcomes of importance to the decision-maker and which can be measured in some form of payoff units (often money).
> - A criterion or analysis rule by which a decision-maker can assess the situation and select a particular strategy.

Regardless of the composition of the decision problem, this decision-making usually occurs in one of three types of environments: decision-making under certainty; decision-making under risk; and decision-making under uncertainty. Decision-making under certainty involves the occurrence where decision-makers know the consequences of every alternative and chooses the alternative with the most favorable outcome.

Decision-making under risk concerns decision-makers' knowledge of the probability of each alternative and their desire to maximize the expected result. Lastly, decision-making under uncertainty concerns the situation where decision-makers have no knowledge of the probabilities of the possible outcomes. (Render and Stair, 1997)

Sage (1991) believes that a fourth environment, decision under conflict, exists and that it is more appropriately handled with game theory and conflict analysis. Problems that arise in the environment of decision-making under the conditions of certainty are usually addressed by deterministic decision theory. Decision analysis models are usually appropriate for dealing with problems associated with decision-making under risk and decision making under uncertainty. The selection of the best engagement activity from a set of alternatives is a problem associated with risk and/or uncertainty.

B. DECISION MODELS

This section describes the system engineering approach to problem solution and the modeling techniques proposed by Sage (1991). The basic guidelines of this approach to problem solution include:

1. Definition of the problem or issue formulation.
2. Analysis of the problem or issue.
3. Interpretation of the analysis, which includes alternative evaluation and selection and implementation.

Under the first guideline, the focus is on the definition of the problem. This formulation process includes identification of the individual problem elements or characteristics. Problem definition is normally a group activity involving those individuals who are most familiar with the issue at hand (e.g., engagement working groups). If done properly, this process identifies the needs, constraints, alterables,

political factors, and military considerations affecting a particular problem. This process should also serve to identify the relationships among these elements.

An important concern in this process is the identification and structuring of the goals and objectives for the alternative that is eventually selected by the decision-makers. Using the concept of collective inquiry, there are two groups of methods for achieving this goal. The first group includes brainstorming, synectics and nominal group technique, all require that a facilitator-led group meet together in same place and at the same time. The nominal group techniques uses the step process of idea generation, discussion, and prioritization and is generally more effective than brainstorming in reducing the influence of dominate personalities. Synectics is based on problem analogies and is considered more appropriate for the generation of truly innovative, unconventional ideas. Also, it normally requires a more experienced facilitator and group. Synectics, along with brainstorming is considered to be directly interactive where nominal is indirectly interactive. Group members using the nominal group technique may not communicate directly.

The second group of collective inquiry includes questionnaires, survey and Delphi. Although these methods do not require the gathering of the group members at a particular time and place, they do tend to take more time to complete. With no interaction among the participants, questionnaires and surveys solicit individual answers to questions from a large group and then derive the overall results. Delphi technique normally requires a written anonymous response over several rounds. The results of each previous round provide feedback to the participants who are asked to comment, revise

and/or reiterate their views. Although this technique may prove to be highly instructive, it can be a lengthy process.

Interaction matrices, trees, structured modeling, and casual loop diagrams are some of the many available element-structuring aids that can be useful during this step. Interaction matrices may be helpful in identifying clusters of closely related elements or identifying the couplings of elements from different sets. Trees are graphical aids that are useful in the portrayal of hierarchical structures. Structured modeling techniques are usually computer aides designed to assists individuals or groups in structuring large sets of elements. Casual loop diagrams provide a graphical heuristic of the casual interactions between sets of variables. The use of any of the available structuring methods can lead to greater clarity of the problem as well as the identification of new or revised descriptions of the problem elements.

The second guideline proposed by Sage focuses on problem analysis and generally consists of two steps. The first step, impact assessment, is the analysis of the alternatives to determine their impact on the overall goal or objective. The second step involves an optimization process, which attempts to maximize the alternatives' performance in terms of goal satisfaction within the stated problem constraints.

Simulation and modeling techniques are very useful for completing this second step. A properly constructed model has the ability to mimic the behavior of real system in a way that allows for experimentation with alternatives that may not be possible with the real system. Since models are dependent on the value system and purpose of use, it is important that one be able to determine the correctness of the model's predictions in

order to validate it. The modeling of systems enhances our ability to comprehend and understand the fine differences in the interrelationships of the system elements and our own relationship to them. Modeling gives decision-makers the ability and opportunity to look at a problem or decision from several different viewpoints and perspectives. The last step in this process begins with the evaluation and comparison of alternatives. After one of the alternatives is selected, an implementation plan is then designed. Sage points out that there is a great distinction between the optimization step of the analysis process and the evaluation of these refined alternatives. Although there must exist more than one alternative for evaluation, it is important for decision-makers to attempt avoid a large number of biases in their evaluation and decision-making. It is the interpretation process of evaluation and decision-making that involves the most interactions with the previous two steps.

Although there are numerous methods available to facilitate evaluation and decision-making, following sections and chapters will focus on the Multi-Attribute Utility Theory and Analytic Hierarchy Process methodologies. MAUT has been designed to provide a methodology for comparing and ranking alternatives that consist of numerous attributes or characteristics. The important attributes are identified, ordered and assigned a relative weight or utility by the decision-maker. The measurement attributes are used in the calculation of an overall utility for each alternative. Additionally, MAUT allows for the use of a variety of utility structures and gives decision-makers the ability to incorporate their attitude toward risk in the utility formula. (Sage, 1991)

The AHP application provides a method for converting subjective judgments into relative values in the absence of physical or statistical measures. AHP decomposes problems by identifying relative factors, making comparative judgments on these elements, and using pairwise comparison matrices to determine the relative importance and overall rating of the available alternatives. (Olson, 1996)

Young (1989), believes that decision-makers can use the benefits of modeling within a Decision Support System (DSS) to help them deal with semi-structured decision problems more effectively and efficiently. Young provides the following list of potential benefits:

1. To more fully understand the implication of one's own judgments, and to modify judgments where they appear to inconsistent with one another or with what is known;
2. To aid effective advocacy by means of more thorough analysis and testing of alternative assumptions and strategic alternatives;
3. To identify decision problems variables to which critical outcomes appear to be most sensitive, so that further efforts at information gathering and analysis can be more effectively directed;
4. To increase the speed and efficiency of analysis so that more alternatives can be examined, thereby increasing the likelihood of identifying a better strategy;
5. To more efficiently and consistently generate, integrate, and judgmentally modify forecasts of outcomes needed for planning.

Although models may not determine the single best strategy for a particular problem, they do provide a heuristic algorithm that almost always provides a better outcome than routine trial and error.

C. DECISION SUPPORT SYSTEMS

The evolution of DSS over the past twenty years has firmly established the purpose of DSS as the provider of resources to be used by decision-makers in the decision-making process. The DSS are available in many makes and models with

varying capabilities. However, all provide information. This information lends credibility to the final decision, but does not become the final decision. The final decisions that include data from the DSS and many other factors are determined by the decision-makers.

Sprague and Carlson (1982) have defined DSS as:

> A class of information systems that draw on transaction processing systems and interacts with other parts of the overall information system to support the decision making activities of managers and other knowledge workers in organizations.

Andriole (1989) agrees with this statement. As Shown in Figure 2.1, he believes that realm of decision support has numerous dimensions. Actual decisions are made at the center, while information and support activities that contribute to the evaluation of options and selection of the final decision reside outside in concentric circles. There are other definitions that are more restrictive while still others appear to be somewhat broader. In either case, Andriole believes that there are many similarities between industry, government and military decision support systems.

Decision support includes all of the supporting data, information, activities and expertise required to arrive at the final selection of alternatives. However, decision support is not completely focused on alternative selection. Valuable decision support information may be provided by other decisions that have no direct connection with the selection of alternatives. (Andriole, 1989)

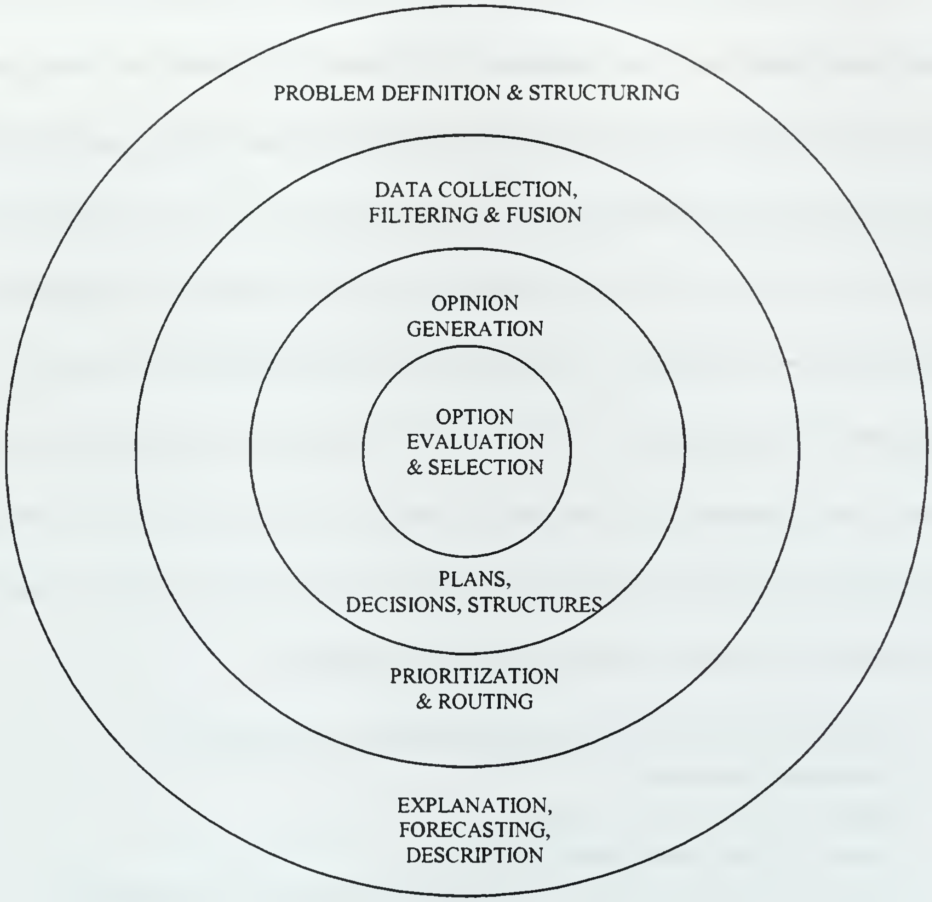

Figure 2.1 - The Range of Decision Support after (Andriole, 1989).

Hogue and Watson (1983) provided that the criteria for a DSS should include the following principles:

- Supports but does not replace decision-making.
- Directed toward unstructured and/or semi-structured decision-making tasks.
- Data and models are organized around the decisions.
- Easy to use software interface.
- Interactive processing.
- DSS use and control is determined by the user.
- Flexible and adaptable to changes in the environment.
- Quick ad hoc DSS building capabilities.

A DSS has the capability to assist decision-makers with many types of decisions depending on system's particular emphasis. DSS have been used to support general long range planning, strategic assessment, operational planning and control, reports and analysis, and general budgeting among others (Meador, 1984). As an example of this, USPACOM is currently developing a Theater Engagement Planning Management Information System (TEPMIS) to assist them in tracking planned and executed engagement activities conducted in their AOR. Although the list of potential applications continues to grow unabated, the fundamental benefits of using a DSS have remained relatively constant. The main benefits of DSS, as derived from numerous studies, are provided below in descending order of perceived usefulness.

- Provide information processing and retrieval capabilities.
- Evaluate alternatives.
- Assist in identifying problems.
- Assist in interpreting information.
- Provide real time analysis of current problems and opportunities.
- Suggest decision alternatives.
- Provide ability to ask what if questions.
- Manage executive time scheduling daily activities.
- Increase decision confidence.

While this list is not all-inclusive, it is indicative of the capabilities desired by senior decision-makers when evaluating or justifying the use of such a system. (Hogue, et al., 1985; Keen, 1981; Meador, et al., 1984; Money, et al., 1988)

The next chapter will provide a basic introduction to the theoretical foundations and applications of MAUT and AHP. It is not the author's purpose to provide a complete

analysis of these two methodologies and all of their potential applications. The fundamental concepts of each methodology are provided in order to provide a better understanding of the capabilities of the software applications.

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III. ALTERNATIVE SELECTION

As the problem concerns the selection of the best engagement activity to achieve a stated goal or objective, this section will focus on two methodologies for completing this task. Both of the multiple criteria decision-making aids addressed here, MAUT and AHP, are concerned with selecting the best choice from a given set of alternatives. Although MAUT is probably the more theoretically accepted approach, AHP is one of the more popular systems in use (Olson, 1996). Before looking at these two methodologies, we must address a problem both of these techniques share, one of determining the numerical value of a subjective judgment.

A. QUANTIFYING SUBJECTIVE JUDGMENTS

Nearly 50 years ago, Stevens (1951) define measurement as "the assignment of numbers to observations according to a set of rules." The assignment of numerical values when measuring objects infers the existence of a scale of measurement. There are four widely accepted and commonly used measurement scales: nominal, ordinal, interval, and ratio. A nominal scale is simply categorizing a set of data into mutually exclusive subclasses. The data contained in these subclasses are counted according to frequency of occurrence. There is no implied order or value. In an ordinal scale, the numbers are assigned to the various instances of the property. This scale of measurement provides data about the order of the categories but does not indicate the level of the differences between them. Interval scales have all the properties of an ordinal scale, and in addition the distances between any two numbers on the scale are equally spaced. This scale of

measurement provides an identity, an order, and a constant unit of measure, which serves to indicate the exact value of an instance in a particular category. A ratio scale has all the characteristics of an interval scale, but it also has a true zero point as its origin and has the property of proportionality. (Rea and Parker, 1997)

These levels of measurement are used in the process of manipulating the numbers into a meaningful value of the object being measured. Steven M. Anderson (1987), a student at the Naval Postgraduate School, proposed that there are four main traditional methods of quantifying subjective judgments. These methods, as presented in his thesis concerning a goal-programming model, are described on the following pages to show their potential for application to the problem at hand.

1. NUMERICAL RATING METHOD

The first method presented by Anderson is the numerical rating method, a very simple and direct method for quantifying subjective judgments. This method was first proposed by Stevens (1951), as a method of obtaining comparative rankings in psychophysical experiments. Using this method, evaluators are asked to associate rated items with fixed reference points by assigning them numbers, or by plotting them as points on a continuous number line. An example of this technique would be the consideration of two engagement activities and their potential effectiveness. A decision-maker wóuld indicate the position of these two alternatives with respect to two other alternatives, one that was not very effective and another highly effective activity. After recording all of the subjective responses, the geometric mean of the numerical estimates

is computed. The continuous number line representation of this example is shown in Figure 3.1.

```
--------------X----------------------X---------------------X--------------------X-------------
  less effective activity        activity 1              activity 2   highly effective activity
```

Figure 3.1 - Numerical Rating Continuous Line.

The primary advantage of the numeric rating method is the simplicity of its computation. It is easy to analyze the results with basic statistics and test for significant differences. The application of a scale relationship between these four activities results in interval scale data that can be transformed into any other kind of scale. The main disadvantage is that there is no natural origin for judgments, and the evaluators frequently disagree with the positioning of reference points. There are also no bounds on the interval scale; the lower bound (not effective situation) of the engagement activity example is set to zero, but there appears to be no upper bound.

2. CATEGORICAL JUDGMENT METHOD

The categorical judgment method, the second method proposed by Anderson, is a commonly used means of obtaining numerical ratings from subjective ratings; wherein evaluators assign instances to previously ordered categories. For example, staff members could be asked to rate the risk of a particular engagement activity according to a scale of high, above average, average, below average, and very low as shown in Table 3.1. This

example uses 25 staff members. The number of categories used can range from two to nine according to desires and resources of the surveyor and the skills of the evaluators (Fink and Kosecoff, 1985).

	HIGH	ABOVE AVG	AVG	BELOW AVG	VERY LOW
Activity A	9	4	6	4	2
Activity B	7	9	7	2	0
Activity C	5	11	8	0	1

Table 3.1 - Initial Rankings of Constant Sum Method.

The item in question is rated and the results are used to construct a matrix of the cumulative frequency data with *n-row* instances and *m-column* categories. Each entry of this matrix represents the number of evaluators who rated instance i in category j. In the cumulative relative frequency matrix c_{ij}, entries are the proportions of the evaluators rating instance i in or below category j. This matrix is shown in Table 3.2.

C_{ij}	HIGH	ABOVE AVG	AVG	BELOW AVG	VERY LOW
Activity A	0.36	0.16	0.24	0.16	0.08
Activity B	0.28	0.36	0.28	0.08	0.00
Activity C	0.20	0.44	0.32	0.00	0.04

Table 3.2 - Constant Sum Method Cumulative Frequency Matrix.

The elements of this matrix are considered as areas under a standard normal curve and are converted to the corresponding z-values. These z-values are then recorded in a z_{ij}

matrix (Table 3.3) consisting of n-rows and $(m-1)$-columns. The rightmost column may be omitted for computational purposes.

Z_{ij}	HIGH	ABOVE AVG	AVG	BELOW AVG
Activity A	0.6406	0.5636	0.5948	0.5636
Activity B	0.6103	0.6406	0.6103	0.5319
Activity C	0.5793	0.6700	0.6255	0.5000

Table 3.3 - Constant Sum Method Standard Normal Matrix.

The row average, r_i, and column average, c_j, are calculated, and a grand average G is found by averaging the column averages. A column sum of squares (SSC) is computed as shown in Equation 3-1:

$$SSC = \sum_j (c_j - G)^2 \tag{3-1}$$

For each row, the row sum of squares (SSR_i) is computed using Equation 3-2:

$$SSR_i = \sum_i (z_{ij} - r_i)^2 \tag{3-2}$$

The scale value of the instances s_i, are found by solving Equation 3-3 in each row:

$$s_i = G - r_i * \sqrt{\frac{SSC_j}{SSR_i}} \tag{3-3}$$

Again, the main advantage of the categorical judgment method is that it obtains values with interval scale properties that can be linearly transformed to any other scale. This method promotes the use of straightforward and uncomplicated questionnaires. Although it is more sophisticated than the numerical rating method, it is still relatively

easy to compute. The major disadvantage of this method is that the precision of its results is limited by the required maximum number of categories selected for use in the survey. (Fink and Kosecoff, 1985) However, this is not a limiting factor in the context of USPACOM's engagement activity selection problem.

3. LEAST SQUARES METHOD

The least squares method is the third method presented by Anderson (1987). The least squares method is a useful and relatively simple means of obtaining scaled interval values from ordinal or comparative judgments. The inputs of this procedure are obtained by asking evaluators to do some ordinal ranking of various instances of a selected property.

This method is begun by recording the responses of the evaluators comparing several items, with respect to a particular like characteristic. For example, a group of senior supporting staff members might be asked to rate three different theater engagement activities for one particular country in terms of the overall impact on the command's theater engagement plan. In this instance, one staff member recommends Activity B over Activity C and Activity B over Activity A. The responses of this particular staff member are contained in the frequency matrix, f_{ij} shown in Table 3.4.

Since Activity B is the preferred engagement activity by the senior staff member, the matrix entries are made in the corresponding rows of the column B that were rated inferior to Activity B. In this instance, entries are made in rows A and C. Since Activity C was the next preferred activity, an entry is made in row A and column C.

f_{ij}	Activity A	Activity B	Activity C
Activity A	--	1	1
Activity B	--	--	--
Activity C	--	1	--

Table 3.4 - Least Squares Method Scoring Matrix.

The responses of all staff members are recorded in this same manner, and collected and recorded in another frequency matrix as shown in Table 3.5. The sum of the cross-diagonal elements of this matrix will be equal to the total number of the staff members. For this example, let's assume that there are 100 staff members. After reviewing each activity and evaluating it on its overall impact on the command's theater engagement plan, 54 staff members ranked Activity A superior to Activity C and 46 staff members ranked Activity C superior to Activity A. Additionally, 72 staff members ranked Activity A superior to Activity B and 28 staff members ranked Activity B superior to Activity A. To complete the matrix, 35 staff members ranked Activity B superior to Activity C and 65 staff members ranked Activity C superior to Activity B.

f_{ij}	Activity A	Activity B	Activity C
Activity A	--	28	46
Activity B	72	--	65
Activity C	54	35	--

Table 3.5 - Least Squares Method Observed Frequency Matrix.

The next step is to convert the frequency matrix to a probability matrix. The probability matrix, p_{ij}, can be calculated by using Equation 3-4:

$$P_{ij} = \frac{f_{ij}}{f_{ij} + f_{ji}} \tag{3-4}$$

For the above example, the probability matrix was obtained and is shown in Table 3.6. Probabilities greater than 0.98 and less than 0.02 should be omitted in order to avoid numerical bias.

p_{ij}	Activity A	Activity B	Activity C
Activity A	0.50	0.28	0.46
Activity B	0.72	0.50	0.65
Activity C	0.54	0.35	0.50

Table 3.6 - Least Squares Method Probability Matrix.

The important thing to note in Table 3.6 is that the diagonal entries of the probability matrix are set equal to 0.5. The probability matrix is then converted to the standard normal matrix, Z_{ij}, by subtracting the mean value of 0.5 from each value of p_{ij} and dividing the differences by the standard deviation of p_{ij}. The Z_{ij} values are the standard normal variables corresponding to the p_{ij} values of the probability matrix. In regards to our example, the Z_{ij} matrix is shown in Table 3.7. The least squares estimate of scale values s_i was obtained by taking the mean of each column in the matrix Z.

As in the previous two methods, the least squares estimate of scale values is also linearly transformable to other scales. Survey and questionnaire forms utilizing this

method along with an ordinal rating scale are simpler and require less time and effort on the part of the evaluators than other methods. Since this method has the advantage of requiring a relatively low level or ordinal assessments, the evaluators can simply list the

Z_{ij}	Activity A	Activity B	Activity C
Activity A	0.000	-0.583	-0.100
Activity B	0.583	0.000	-0.385
Activity C	0.100	0.385	0.000
$\sum Z_{ij}$	0.683	-0.198	-0.485
$s_i=1/n*\sum Z_{ij}$	0.227	-0.066	-0.161

Table 3.7 - Least Squares Method Standard Normal Matrix.

instances in the order of importance regarding the compared factor. As shown in the example, the main disadvantage of this method is that it requires a large number of evaluators to produce a reasonably accurate probability matrix. Although this example used 100 evaluators, the number of actual experts resident on most military staffs is significantly smaller and would preclude the use of this method. Another issue resides in the cases where the evaluators do not rank all instances for various reasons, which makes the least squares procedure difficult to use in scale development.

4. CONSTANT SUM METHOD

The final method presented by Anderson is the constant sum method, a method developed by Comrey (1950) that quantifies subjective ratings using pairwise

comparisons. In this method, each activity is compared with each other by splitting 100 points. There will be $n(n-l)/2$ pairs that must be considered, and 100 points will be divided between each activity in accordance with an absolute ratio of the greater to the lesser. For example, if a staff member gives 80 points to Activity A and 20 points to Activity B, this indicates that Activity A is four times more important than Activity B. In the same manner a split of 60-40 would indicate a ratio of three to two, and 50-50 that two instances have the same magnitude.

An example is used to illustrate this procedure. Suppose two staff members are asked to evaluate three plans on the basis of their content. Table 3.8 represents their respective comparison matrices where p_{ij} is the number of points is given to plan i when compared with plan j. Both staff members preferred plan A to B, plan A to C, and plan C to B, but the intensities of their endorsements are different.

	Staff Member 1			Activity B	Staff Member 2		
p_{ij}	A	B	C	p_{ij}	A	B	C
Activity A	50	20	70	Activity A	50	30	40
Activity B	80	50	60	Activity B	70	50	80
Activity C	70	40	50	Activity C	60	20	50

Table 3.8 - Constant Sum Method Comparison Matrix.

The next step is to construct a matrix V by averaging the p_{ij} values across evaluators as shown in Table 3.9.

V_{ij}	Activity A	Activity B	Activity C
Activity A	50	25	55
Activity B	75	50	70
Activity C	65	30	50

Table 3.9 - Constant Sum Method Average Comparison Matrix.

Another matrix W is formed from matrix V_{ij}. The w_{ij} values are computed using the Equation 3-5 and the W matrix for this example is shown in Table 3.10:

$$w_{ij} = \frac{v_{ij}}{v_{ji}} \tag{3-5}$$

W_{ij}	Activity A	Activity B	Activity C
Activity A	1.000	0.333	0.846
Activity B	3.000	1.000	2.333
Activity C	1.181	0.428	1.000

Table 3.10 - Constant Sum Method W Matrix.

As shown in Equation 3-6, the scale values can be computed by taking the n^{th} root of each column product, where n is the number of instances compared in this example.

$$s_j = (\Pi w_{ij})^{\frac{1}{n}} \tag{3-6}$$

The calculation and final results of this example are shown in Table 3.11.

$s_1 = [\ (1.000) * (3.000) * (1.181)\ ]^{1/3} = 1.524$
$s_2 = [\ (0.333) * (1.000) * (0.428)\ ]^{1/3} = 0.522$
$s_3 = [\ (0.846) * (2.333) * (1.000)\ ]^{1/3} = 1.254$

Table 3.11 - Constant Sum Method Scale Value Calculation.

The constant sum method provides quantitative values that allow linear transformations and all arithmetic operations. The scale, therefore, presses ratio properties rather than interval scale properties. Its advantage over the previous methods lies in the fact that all of the quantitative values are on a similar ratio scale vice an interval scale. When using this method with a large number of instances, consistency becomes a problem due the potential for self-contradiction by the evaluators.

Although each of these methods present several advantages in quantifying subjective judgments, none of them, in and of itself is adequate for addressing the stated problem. The next two sections will examine two other, somewhat more robust, methods of performing this task.

B. MULTI-ATTRIBUTE UTILITY THEORY

Decomposition of the object to be evaluated into relevant dimensions through the use of a hierarchical, descriptive model is the principle concept of Multi-Attribute Utility Theory (MAUT). The lowest level hierarchical dimensions are considered operational. This indicates that they are measurable attributes of the evaluation object. Each element of the hierarchy is assigned a weight, which represents its relative importance in the overall hierarchy. Additionally, attributes at the lowest level are assigned utility

functions, which determine the utility for each plausible value of the attribute.

The rigorous application of objective measurement to decision-making is the approach attempted by utility theory. This decision analysis methodology presupposes that better decisions will result from the rational and unbiased comparison of measurable attributes of performance alternatives. An alternative's value is assumed to consist of measures over the criteria that contribute to its overall worth. All of these values are converted to some common scale of utilities. (Olson, 1996)

Utility theory assumes that the each alternative's performance on each criterion is known by decision-makers. A single-measure utility function (SUF) is used to measure potential performance levels on each criterion. These measures are generally characterized, as more of a good thing is better than less. Although their measurement values are considered continuous, continuous scales of value are not required of alternatives. After identifying the single-measure utility functions, the value of each alternative is measured by an overall utility function. While this overall utility function weights each of the criteria of value, this weighting does not necessarily have to be linear. (Olson, 1996)

The basic hypothesis of MAUT states that there exists a real valued function U defined on the set of feasible alternatives for any decision problem. Whether done consciously or not, it is this utility function that decision-makers wish to maximize. The role of the analyst is to determine the function that aggregates the criteria $g_1, g_2,.., g_k$. Bunn (1984) believes that utility consists of the following theoretical assumptions.

- Structure - The choices available to the decision-maker can be sufficiently described by the payoff values and associated probabilities of those choices. This implies that the value of a choice consists of the choice's measures on factors of value to the decision-maker.
- Ordering - The decision-maker can express preference or indifference between any pair of tradeoffs.
- Reduction of Compound Prospects – Decision-makers are indifferent between compound prospects and their equivalent simple prospects. This implies that decision-makers give no value to playing the game, or gambling, or working in a business that is exciting because it is risky.
- Continuity - Every payoff can be considered to be a certainty equivalent for the prospect of some probability *p* of the worst outcome and the inverse probability (*1-p*). This assumption implies that severe outcomes would be risked at some small probability.
- Substitutability - Any prospect can be substituted for by its certainty equivalent.
- Transitivity of Prospects – Decision-makers can express preference or indifference between all pairs of prospects. This extends the assumption of ordering of payoffs to prospects.
- Monotonicity - For two options with the same payoffs, decision-makers should prefer the option with the higher probability of the better payoff. Cases where this is not demonstrated imply that there is some other factor of value that has not been considered.

Additionally, Bunn indicates that there are some caveats to utility theory. As opposed to descriptive measures, which describe how decision-makers behave, utility theory is normative, describing how decision-makers should behave. One must realize that the behavior of many successful decision-makers is very much in violation of the above assumptions. Utility values are not necessarily additive in that $U(A + B)$ may not be equal to $U(A) + U(B)$. This indicates the reasonable possibility that utility functions can curve. It is important to note that numerical scale of utility theory is intended to order preferences, not to measure their strengths. Lastly, utilities are personal attributes representative of a particular decision-maker and do not carry over to others. (Olson, 1996)

Marshall and Oliver (1995) explain that it is seldom possible for decision-makers to quantify every attribute in a decision problem. In fact, they believe that as the level of the decision increases, the more difficult it becomes for one to apply some form of direct measurement. While it is relatively simple to preferentially order a single attribute, it is much more difficult for decision-makers to compare results with multiple attributes. A MAUT model where each attribute is assigned a separate, nonlinear utility function allows each attribute to be considered independently of the other attributes and is defined in the following paragraphs.

The set of all possible attribute results ($j = 1, 2, \ldots, n$) is known as R_j. Assuming that a preference ordering is defined on each of these sets, the scalar utility from this vector of attributes is shown in Equation 3-7

$$U(r) = \sum_{j=1}^{n} k_j u_j(r_j) \tag{3-7}$$

where u_j is a utility function defined on R_j, k_J is the relative weight of attribute j, r_j is an element of R_J, and $\mathbf{r} = (r_1, r_2, \ldots r_n)$. In this particular description, along with the first two assumptions of basic utility theory, it is necessary to prescribe some additional assumptions to ensure that Equation 3-7 holds.

The first assumption of basic utility theory states that every pair of elements in set R can be compared, and there exists a well-defined preference ordering of the elements. So if r_1 and r_2 are any two elements of set R, one should use the following symbology to define their relationships. Use $r_1 > r_2$, if result r_1 is preferred to r_2, $r_1 \sim r_2$, if result r_1 is equally preferred to r_2, and $r_1 < r_2$, if result r_2 is preferred to r_1. The second assumption

involves the concept of transitive preference ordering, which implies that if one prefers r_1 to r_2, and r_2 to r_3, then one must prefer r_1 to r_3. It is assumed that at least one of these hold if $r_j^{(1)}$ and $r_j^{(2)}$ are any two results in R_j. The "Best Result" and "Worst Result" for any attribute j is denoted as $\overline{r}_j$ and $\underline{r}_j$, respectively so that $\overline{r} = (\overline{r}_1, \overline{r}_2, \ldots, \overline{r}_n)$ and $\underline{r} = (\underline{r}_1, \underline{r}_2, \ldots, \underline{r}_n)$. The inclusion of these assumptions is to ensure consistency when comparing results. (Marshall and Oliver, 1995)

Additionally, the following four concepts are used in determining the restrictions on the preference ordering and must be applied to ensure that the utility function decompositions hold:

1. Preferential Independence (PI) – Given $r_j^{(1)} \in R_j$, and $r_j^{(2)} \in R_j$, and $r_1 \in R_1$, every attribute j is said to be PI of attribute 1, if $r_j^{(1)} > r_j^{(2)}$ for every r_1.
2. Mutual Preferential Independence (MPI) – Attribute j is said to be MPI of attribute 1, if j is PI of 1 and 1 is PI of j.
3. Utility Independence – As shown in the decision sapling in Figure 3.2, choose any attribute set N, and choose any three values from R_1, such that $r_j^{(1)} > r_1 > r_j^{(2)}$, then choose any vector **s** which is an element of $R_2 \times R_3, \ldots, \times R_n$. Attribute 1 is said to be utility independent of its complement, if the indifference probability p stays unchanged for every possible s.
4. Mutual Utility Independence (MUI) – The subset of attributes and its complement are said to be MUI, if a subset of attributes is utility independent of its complement and vice versa. (Marshall and Oliver, 1995)

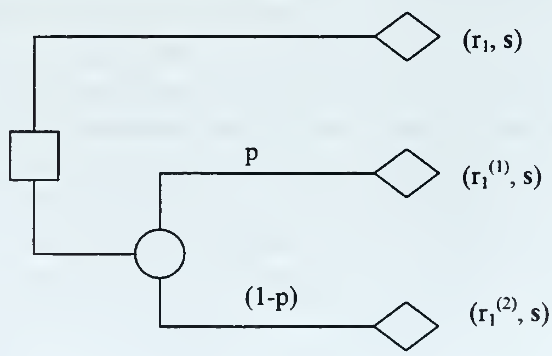

Figure 3.2 - Diagram of Utility Independence after (Marshal and Oliver, 1995).

It is worth noting that the first two concepts extend to the attribute subsets and the third concept can be extended to any subset of attributes and its complement. The assumption of utility independence is much stronger than preferential independence. Also, attribute set *N* must have the MPI property if the decomposition of the utility function into its additive form is to be considered valid. However, this is not considered to be sufficient. The more complex multiplicative form is shown in Equation 3-8.

$$U(r) = \frac{\prod_{j=1}^{n}\left[1 + Kk_j u_j(r_j)\right] - 1}{K} \tag{3-8}$$

Using Equation 3-8, recognize that $\mathrm{U}(\underline{\mathrm{r}}) = 0$ and $\mathrm{U}(\bar{\mathrm{r}}) = 1$. This is necessary to scale U(**r**) on (0,1). Also *K* must satisfy Equation 3-9

$$1 + K = \prod_{j=1}^{n}(1 + Kk_j). \tag{3-9}$$

One of the important results of MAUT is that the decomposition of Equation 3-8 only holds if the set of *N* attributes has the property of MUI. This result allows single-attribute utility functions to be combined in the same manner as multiplicative utility functions when MUI holds. However, certain conditions must be met concerning the weights k_j if the additive form of Equation 3-8 is to be considered valid. (Marshall and Oliver, 1995)

In determining the k_j's, if we let $\underline{r}(j)$ be the vector with all attributes set to their worst result except the *j*th, which is set to its best (for an arbitrary *j*), as shown in Equation 3-10.

$$U(\underline{r}(j)) = k_j \tag{3-10}$$

By comparing the certainty of getting $\underline{r}(j)$ to the gamble between $\bar{r}$ and $\underline{r}$ on a decision sapling, the indifference probability is k_j. After applying the decision-maker's judgment in determining the k_j's, one must determine if these weights add to 1. If they do, then the solution to Equation 3-9 results in $K = 0$, Equation 3-8 simplifies to Equation 3-7 and the principle of additive utility holds. (Marshall and Oliver, 1995)

If the k_j's do not add to 1, but the principle of MUI holds, U can written in terms of the individual utility functions (u_j's) using the utility function's multiplicative form (Equation 3-8). From this it can be shown that

1. If $\sum_{j=1}^{n} k_j > 1$, K is the unique root of Equation 3-9 in (-1,0).

2. If $\sum_{j=1}^{n} k_j < 1$, K is the unique root of Equation 3-9 in (0,∞).

In order to show that N has the MUI property, decision-makers must check 2^n-2 subsets. However, decision-makers can reduce the amount of checking by using the following algorithm. Find an attribute that is utility independent of its complement and number it 1. Then check to see if each of the (n-1) pairs {1,j} is preferentially independent of its complement. This requires the making a total of n checks of which (n-1) are for the simpler verification of preferential independence rather than utility independence. (Marshall and Oliver, 1995)

Continuing with the theme of selecting the best engagement activity, the following is a simplified example of the MAUT process. In this example Goodwill Relations, Improved Access, and Develop Coalition Partner represent the three engagement strategies. As shown in Table 3.12, each of these decision factors is

assigned a level of relative importance on a scale of 0 to 1. The sum of all of these decision factors must sum to one.

FACTOR	IMPORTANCE
Goodwill Relations	0.3
Improved Access	0.5
Coalition Partner	0.2
Total	1

Table 3.12 - Relative Importance of MAUT Decision Factors.

Each of the engagement strategies will use a number of alternative engagement activities to achieve its objective. As before, each alternative engagement factor (Table 3.13) is assigned a relative importance on a scale of 0 to 1.

FACTOR	GOODWILL RELATIONS	IMPROVED ACCESS	COALITION PARTNER
Port Visits	0.8	0.7	0.5
Education	0.7	0.4	0.6
Exercises	0.5	0.8	0.5
Conference/Mil Talks	0.6	0.7	0.5
Exchange	0.7	0.5	0.7
High Level Visit	0.8	0.8	0.7
Foreign Military Sales	0.6	0.6	0.6

Table 3.13 - Relative Importance of MAUT Alternative Factors.

The weighted evaluation for each individual category is the product of each factor weighted and the factor evaluation of each alternative. Sum up each product (of the factor and factor evaluation) to obtain the total weighted evaluation for a particular alternative. The example shown in Table 3.14 shows the evaluation of the Port Visits

alternative as it applies to the strategies of Goodwill Relations, Improved Access and Develop Coalition Partner.

After completing this process for each alternative to be considered under the three engagement strategies, compare the total weighted evaluations. The alternative that has the highest total weighted evaluation is considered the best choice.

FACTOR NAME	FACTOR WEIGHT (IMPORTANCE)	PORT VISITS FACTOR EVALUATION	WEIGHTED EVALUATION
Goodwill Relations	0.30	0.8	0.24
Improved Access	0.50	0.7	0.35
Coalition Partner	0.20	0.5	0.10
TOTAL	1	No Total Here	0.69

Table 3.14 - Evaluation of Port Visits vs. Individual Theater Engagement Plan Categories.

Although the above example was simplified for ease of computation, one can see that multi-factor decision making can be somewhat complicated. The use of this methodology requires decision-makers to consider all of the various factors subjectively and intuitively in making the ultimate selection. After careful consideration, all of the important factors can be given appropriate weights and each alternative can be evaluated in terms of these factors. Keeny and Raiffa (1993) provide more detailed information on MAUT.

C. ANALYTICAL HIERARCHY PROCESS

The majority of the background information in this section on the Analytic Hierarchy Process (AHP) is drawn from the writings of Dr. Thomas L. Saaty. Saaty

developed the process in the early 1970's and has continually work to improve it since that time. Saaty has written several books on AHP, co-authored others, and has also authored numerous articles concerning the value and validity of this process. Additionally, Saaty and Dr. Ernest H. Forman have developed a mature software version that has proven useful in hundreds of applications in over 27 different problem types including determining requirements, resource allocation, measuring performance, conflict resolution and choice of best policy alternative. (Saaty and Vargas, 1989)

Specific military examples of the use of AHP and Expert Choice™ include vendor selection by the US Navy and the Joint Chiefs of Staff, resource allocation and research and development project selection by the US Army and force restructuring problems by the Department of Defense.

Saaty believes that the proper arrangement of the decision factors in a hierarchic structure descending from an overall goal to criteria, subcriteria and alternatives is important. Saaty (1980) states that "a hierarchy is an abstraction of the structure of a system to study the functional interactions of its components and their impacts on the entire system." The decision-maker must include enough decision details to:

> represent the problem as thoroughly as possible, but not so thoroughly as to lose sensitivity to change in the elements; consider the environment surrounding the problem; identify the issues or attributes that contribute to the solution; and identify the participants associated with the problem (Saaty, Management Science, 1990).

The arrangement of the hierarchy in this manner provides an overall view of situation's complex relationships and helps the decision-maker determine if the issues in each level are in the same category so he can make accurate comparisons. It is important

to note that these hierarchies need not be complete. An element at a particular level may not necessarily be an attribute of all the elements in the next subordinate level. Hierarchies are not the same as traditional decision trees as each separate level may represent different views of the same problem. (Saaty, Management Science, 1990)

The next step in the analytic hierarchy process involves the conversion of subjective judgments of the decision into numerical values. As will be shown, AHP uses a somewhat different technique than those previously discussed. Saaty states that there are four major steps used in this process:

1. Break the decision problem into hierarchical levels.
2. Collect input data by pairwise comparisons of decision elements.
3. Using the eigenvalue method to estimate the relative weights of decision elements.
4. Aggregate the relative weights at each level.

The analytical hierarchy process is better suited to situations where decision-makers have difficulty in accurately determining the various factor weights and evaluations. A hierarchy of criteria and alternatives allows decision-makers to decompose the information contained in a decision problem. Using informed judgments to derive the weights and priorities, both qualitative and quantitative criteria can be compared. (Saaty, 1982) Again, the three most important steps in the process are to state the objective, define the criteria, and pick the alternatives. Patrick Harker, Decisions Science Department, The Wharton School, University of Pennsylvania states that "the overall philosophy of the AHP is to provide a solid, scientific method (the analytic part) to aid in the creative, artistic formulation and analysis of a decision problem (Golden, et al, 1989)."

The theoretical foundation of AHP is based on a set of four axioms. The first axiom states that given any two alternatives i and j out of the set A, the decision-maker will be able to complete a pairwise comparison a_{ij} of the alternatives under any criterion c from the set of criteria C. Each element a_{ij} of the pairwise comparison matrix is the reciprocal of a_{ji}, or as shown in Equation 3-11.

$$a_{ij} = \frac{1}{a_{ij}} \quad \forall i, j = 1,2,\ldots,n \tag{3-11}$$

The second axiom states that when comparing alternatives, the decision-maker never judges one to be infinitely better than the other, or $a_{ij} \neq \infty$ for all i, j in set A. The third axiom states that the decision-maker can formulate the problem as a hierarchy. Lastly, the fourth axiom states that the hierarchy represents all of the alternatives and criteria that impact on the problem. The alternatives and criteria must represent the decision-maker's intuition and should be assigned compatible priorities. (Vargas, 1990)

To begin the process, the decision-maker must decide which of the stated objectives is most important as compared to the others. This process is known as pairwise comparisons and begins by laying out the overall hierarchy of the decision. This hierarchy serves to reveal the factors for consideration as well as various alternatives in the decision. Following this, pairwise comparisons are made which result in the determination of factor weights and factor evaluations. The alternative with highest total weighted score is selected as the best alternative. (Saaty and Alexander, 1989)

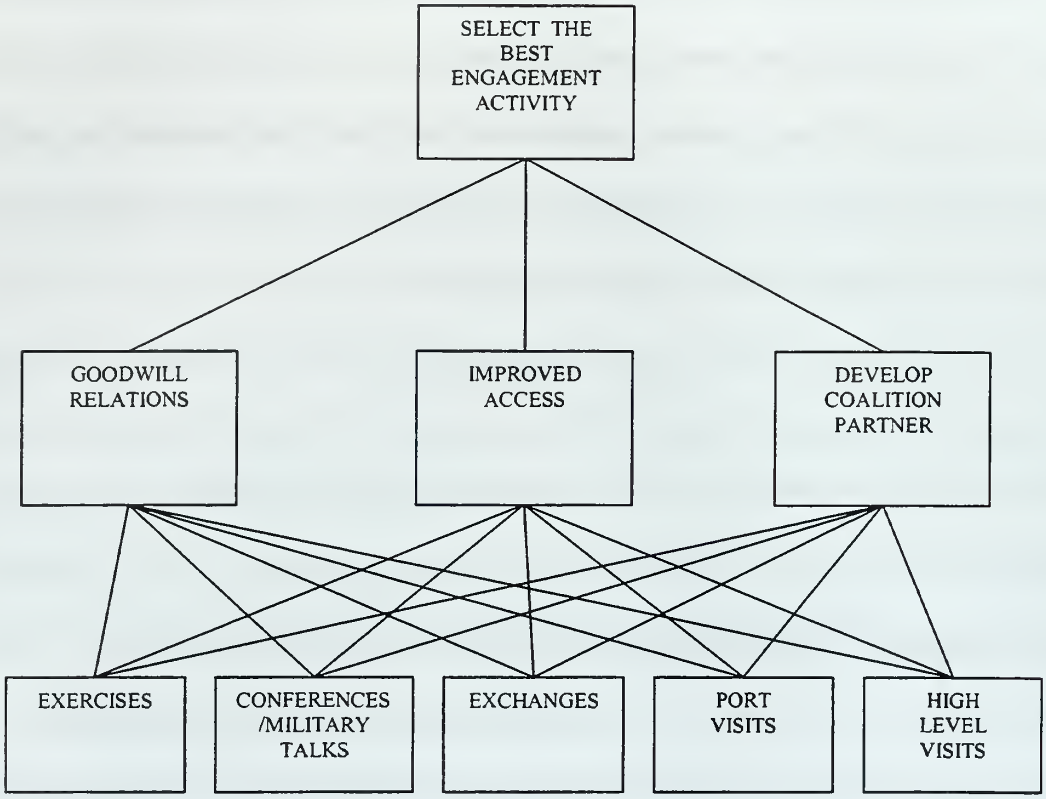

Figure 3.3 - Decision Hierarchy for Engagement Activity Selection after (Saaty and Vargas, 1982).

As depicted in Figure 3.3, the hierarchical breakdown for selecting the best engagement activity in this example has three levels. The top level describes the overall decision. The second level describes the factors (goals/objectives) that are to be considered. The lower level of the hierarchy depicts the alternative engagement activities. Another level below (not shown here) the alternatives would contain the attributes of these alternatives or could use some sort of measurement scale to depict an absolute measure of effectiveness for each alternative.

Each of the three main goals/objectives is connected to each and every one of the alternative engagement activities. (Saaty and Vargas, 1982) The use of hierarchies

allows the decision-maker to focus on each element of the decision-making process separately. According to Saaty (Management Science, 1990), it is more effective for the decision-makers to focus their judgment on a pair of elements and use a single property for comparison between the two without regard for the other properties or elements. Using pairwise comparison, two alternatives will be evaluated on a relative scale. The decision-makers can define the pairwise comparisons in any manner they choose.

However, the prime consideration is that the pairwise comparisons accurately reflect the decision-makers' judgment on how they want to measure their alternatives. Additionally, the pairwise comparisons should be listed in an ordinal fashion. Due to the large number of pairwise comparisons that would have to be made with large matrices, Saaty has recommended keeping the number of elements in any level at no more than nine (7+/-2) and the number of levels between three and five. It is obvious that the number of necessary pairwise comparisons will increase exponentially as the numbers of levels are increased. The pairwise comparison definitions listed in Table 3.15 from (Saaty and Alexander, 1989) will be used for the purpose of demonstrating this technique.

Pairwise comparison in AHP is predicated on the premise that the decision-maker needs to evaluate a problem consisting of m criteria and n alternatives. As in the constant sum method, in order to evaluate m criteria, each decision-maker must make $m(m-l)/2$ pairwise comparisons (where m is the number of elements on a level of the hierarchy). Constructing a comparison matrix, the decision-maker uses m rows and m columns to represent each attribute. (Saaty, 1989)

As stated in the axioms, AHP requires that the matrix be reciprocal. Additionally, the main diagonal elements of the matrix will have the value of unity ($a_{ii} = 1, \forall i = 1,2,\ldots m$). The pairwise comparison procedure is performed at every level of the hierarchy, with the exception of the alternatives themselves, which are the lowest level of the hierarchy. In other words, if there were one or more levels of subcriteria, pairwise comparisons in the manner described above would be performed. In the final or lowest level of the hierarchy, decision-makers would make a pairwise comparison of the alternatives one attribute at a time. Decision-makers would then evaluate each alternative by attribute. Ultimately, the decision-makers will have m matrices (one for each attribute) of size $n \times n$. (Saaty, 1989)

The pairwise comparison matrices are said to be consistent if there is a vector a of size n, in the case of alternatives (a would be of size m in the case of attributes), such that Equation 3-11 holds. Otherwise, the matrix is not considered to be consistent. These equations imply that

$$r_{ij} = r_{ik} \times r_{kj} \quad \forall i,j,k \tag{3-11}$$

for consistency. The vector a is made unique through normalizing by dividing by its sum. Therefore,

$$\sum a_i = 1 \tag{3-12}$$

If we refer to the matrix of pairwise comparisons as R; R is consistent if, and only if $Ra = na$, where $a = (a_1, a_2, \ldots, a_n)$ represents the vector of actual weights and n represents the number of elements. In a decision problem where some inconsistency is present, AHP presupposes that the decision-maker does not know a and cannot produce

Numerical Values (Intensity of Importance)	Definition	Remarks
1	Equally preferred	Two activities contribute equally to the objective
3	Moderately preferred	Experience and judgment slightly favor one activity over another
5	Strongly preferred	Experience and judgment strongly favor one activity over another
7	Very strongly preferred	An activity is strongly favored and its dominance over the other has been demonstrated in practice
9	Extremely preferred	The evidence favoring one activity over another is of the highest possible order of information
2,4,6,8	Intermediate values between 2 adjacent judgments	Used when a compromise between judgments must be reached (consensus)
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared to *I*	Used to reflect the dominance first alternative as compared with the second
Rationals	Ratios arising from scale	If consistency were forced by obtaining *n* numerical values to span the matrix

Table 3.15 - The AHP Point Scale for Pairwise Comparisons.

the pairwise relative weights of matrix R accurately. In this instance, AHP solves

$$R'a' = \lambda_{\max} a' \tag{3-13}$$

where R' is the matrix of observed pairwise comparisons, λ_{max} is the principal eigenvalue of R', and a' is the right eigenvector of R' (Zahedi, 1986). This leads to an approximation of a, whose entries correspond to the weights of the alternatives or

attributes. To determine the amount of inconsistency and determine if the amount of consistency is acceptable, Saaty developed the consistency index (CI) defined as

$$CI = \frac{(\lambda - n)}{(n - 1)} \tag{3-14}$$

where n represents the number of alternatives being compared.

Saaty explains that this definition of consistency goes beyond the traditional requirement of preference transitivity (if A is preferred to B and B is preferred to C, then A must be preferred to C) to include the actual transitive intensity with which the preference is expressed through the comparable alternatives. Saaty defines the concept of cardinal consistency in the strength of the preference as follows; if A is twice as preferable to B and B is three times preferable to C, then A must be six times as preferable to C. Saaty states that "inconsistency is a violation of proportionality which may or may not entail the violation of transitivity (Saaty, 1980)." Saaty further states that "our study of inconsistency demonstrates that it is not whether we are inconsistent on particular comparisons that matters, but how strongly consistency is violated in the numerical sense for the overall problem under study (Saaty, 1980)." If the CI $\leq$ 0.10, the decision-maker should accept the estimate of a. Otherwise, the decision-makers should revise some of their judgments during the pairwise comparisons in an attempt to improve their consistency. (Saaty, 1980)

Decision-makers could be forced into consistency by making just n pairwise comparisons in the first row of the pairwise comparison matrix. In this instance, the first pairwise comparison would be alternative one compared to itself, which is by definition

unity. Excluding this comparison, *(n-1)* pairwise comparisons are all that are necessary. In this way, decision-makers would obtain the entries for the first row of the pairwise comparison matrix, and define the weights based on those entries. The entries for the rest of the matrix could be obtained by using Equation 3-13. Again, the weights would be normalized to sum to one. With these weights obtained exclusively from the first row of the pairwise comparison matrix, every element of the matrix could be obtained. The resulting matrix R would be perfectly consistent. (Golden, et al, 1989)

As indicated, AHP does not force this consistency on decision-makers. By requiring $n(n-1)$ comparisons, AHP makes the vector a over-determined and allows inconsistencies. Therefore, the pairwise comparison matrix could very likely contain inconsistencies. With the presence of these inconsistencies, there is no exact solution for the vector a, such that Equation 3-11 holds for every i and j. The question is how to find an a that "best" fits these equations when inconsistency is present. The advantages of the eigenvalue method are (1) if the pairwise comparison matrix is consistent, $\lambda_{max} = n$ and (2) it allows evaluation of consistency by the consistency index (CI) defined above in Equation 3-14. (Saaty and Alexander, 1989)

As an example, using the hierarchy in Figure 3.3, the decision-makers begin at the top level of the hierarchy by looking at their goal/objective and comparing the relative importance of Goodwill Relations, Improved Access and Coalition Partner engagement strategies in achieving this objective. Using the scale contained in Table 3.16, the next step will involve the determination of the relative importance of individual engagement activities under each of the engagement strategies. For the simplicity of this example, we

will assume that all three of the engagement strategies are equally important. Under the strategy of Goodwill Relations, the decision-makers determine that Port Visits are *extremely preferred* to Exchanges (score of 9). The decision-makers also determine that High Level Visits are *very strongly preferred* to Exchange activities (score of 7) as a measure of effectively conducting Goodwill Relations. Lastly, the decision-makers determine that Port Visits are *moderately preferred* to High Level Visits (score of 3).

Goodwill Relations	Port Visits	High Level Visits	Exchanges
Port Visits		3	9
High Level Visits			7
Exchanges			

Table 3.16 - Initial Pairwise Comparison of Alternatives.

Based on the information in the preceding paragraph, the AHP technique allows the decision-makers to determine the evaluation factors for the three engagement activities under the single goal of Goodwill Relations. As shown in Table 3.17, the comparison of each alternative against itself results in the assigned value of 1, which represents *equally preferred*.

Goodwill Relations	Port Visits	High Level Visits	Exchanges
Port Visits	1	3	9
High Level Visits		1	7
Exchanges			1

Table 3.17 - Pairwise Comparisons of Alternatives Against Themselves.

In general, for any pairwise comparison matrix, the value of 1 will be placed down the diagonal from the upper left corner to the lower right corner. To finish the matrix, AHP makes the observation that alternative A is twice as preferred to alternative

B, the decision-maker can conclude that Alternative B is preferred only half as much as alternative A. Therefore, if alternative A receives a score of 2 relative to alternative B, then alternative B should receive a score of ½ when compared to alternative A. This same logic is used to complete the lower side of the matrix. As defined by the axioms, the values of the lower side of the matrix are the reciprocals of the value located directly diagonal across their location. The values should be as depicted in Table 3.18.

Goodwill Relations	Port Visits	High Level Visits	Exchanges
Port Visits	1	3	9
High Level Visits	1/3	1	7
Exchanges	1/9	1/7	1

Table 3.18 - Pairwise Comparisons of Reciprocal Alternatives.

The next step in the process, as shown in Table 3.19, involves the conversion of the fractions into decimal numbers and the summing of the column totals.

Goodwill Relations	Port Visits	High Level Visits	Exchanges
Port Visits	1	3	9
High Level Visits	0.3333	1	7
Exchanges	0.1111	0.1428	1
Total	1.4444	4.1428	17

Table 3.19 - Conversion of Pairwise Comparison Fraction into Decimals.

Once each column has been totaled, each number in the matrix is divided by their respective column totals as shown in the following table. Each column total must equal 1 (due to computational rounding, the results shown in Table 3.20 will only approximate 1, but has no significant effect on the final values).

Goodwill Relations	Port Visits	High Level Visits	Exchanges
Port Visits	0.6923	0.7241	0.5294
High Level Visits	0.2307	0.2414	0.4118
Exchanges	0.0769	0.0344	0.0588
Total	0.9999	0.9999	1

Table 3.20 - Normalization of Pairwise Comparisons.

To determine the priorities of Goodwill Relations for the three alternative engagement activities, simply find the average of the various rows from the matrix of numbers as shown in Table 3.21.

Goodwill Relations	Port Visits	High Level Visits	Exchanges	Row Average
Port Visits	0.6923	0.7241	0.5294	0.6486
High Level Visits	0.2307	0.2413	0.4117	0.2946
Exchanges	0.0769	0.0344	0.0588	0.0567

Table 3.21 - Row Averaging of Pairwise Comparisons.

As shown in Table 3.22, Port Visits provides the highest factor evaluation as a measure of effectiveness for Goodwill Relations. All of the other factor evaluations for the other alternatives can be determined in the same fashion.

FACTOR	Port Visits	High Level Visits	Exchanges
Goodwill Relations	0.6486	0.2946	0.0567

Table 3.22 - Factor Evaluation for Goodwill Relations.

Now that the factor evaluations have been completed the decision-makers must conduct one additional process to ensure that all of their responses have been consistent. The consistency ratio can be obtained by determining the weighted sum vector (WSV) of

the matrix. Using the product of factor evaluation for the first alternative (A_1) from Table 3.23 and the values of the first column (B_{11}, B_{12}, B_{13}) of the original pairwise comparison matrix (Table 3.19) initiates this process. After completing the same process for the second and third alternative, sum these values over the rows as shown in Equation 3-15.

$$WSV = \begin{bmatrix} (A_1)(B_{11}) + (A_2)(B_{12}) + \cdots (A_n)(B_{1n}) \\ (A_1)(B_{21}) + (A_2)(B_{22}) + \cdots (A_n)(B_{2n}) \\ \vdots \\ (A_1)(B_{n1}) + (A_2)(B_{n2}) + \cdots (A_n)(B_{nn}) \end{bmatrix} = \begin{bmatrix} WS \\ WS_2 \\ \vdots \\ WS_n \end{bmatrix} \tag{3-15}$$

$$WSV = \begin{bmatrix} (0.6486)(1) + (0.2946)(3) + (0.0567)(9) \\ (0.6486)(0.3333) + (0.2946)(1) + (0.0567)(7) \\ (0.6486)(0.1111) + (0.2946)(0.1428) + (0.0567)(1) \end{bmatrix} = \begin{bmatrix} 2.0427 \\ 0.9077 \\ 0.1708 \end{bmatrix}$$

The consistency vector (CV) must be determined next. As shown in Equation 3-16, this step is completed by dividing the results of the weighted sum vector by the alternative factor evaluations contained in Table 3.22.

$$CV = \begin{bmatrix} \frac{WS_1}{A_1} \frac{WS_2}{A_2} \cdots \frac{WS}{A_n} \end{bmatrix} = \begin{bmatrix} C & C_2 \cdots C_n \end{bmatrix} \tag{3-16}$$

$$CV = \begin{bmatrix} \frac{2.0427}{0.6486} & \frac{0.9077}{0.2946} & \frac{0.1708}{0.0567} \end{bmatrix} = \begin{bmatrix} 3.1493 & 3.0811 & 3.0123 \end{bmatrix}$$

Upon completion of these two steps, decision-makers must compute the consistency index (CI) and lambda (λ) before determining the final consistency ratio.

Lambda is simply the average value of the consistency vector and is computed using Equation 3-17.

$$\lambda = \frac{(A_1 + A_2 + \cdots A_n)}{n} \tag{3-17}$$

$$\lambda = \frac{3.1493 + 3.0811 + 3.0123}{3} = 3.0809$$

The formula for determining the CI has been previously defined as Equation 3-14. In this example, $n = 3$, for the three different alternatives being compared.

$$CI = \frac{(3.0809 - 3)}{(3 - 1)} = 0.0405$$

Finally, the Consistency Ratio (CR) can be computed. The CR is equal to the CI divided by the Random Index (RI) as shown in Equation 3-18. The RI is a direct function of the number of alternatives being considered. The RI values in Table 3.23 were obtained by computing the eigenvalues for each n-size matrix using a sample size of 500.

n value	RI
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Table 3.23 - AHP Random Index Table.

$$CR = \frac{CI}{RI} \tag{3-18}$$

$$CR = \frac{0.0405}{0.58} = 0.0698$$

For this example, CR = 0.0698. The consistency ratio tells decision-makers how consistent they are with their answers. A higher number indicates less consistency, whereas a lower indicates more consistency. As previously discussed, generally, if the consistency ratio is 0.10 or less, the decision-makers' answers are relatively consistent. As shown above, the decision-makers' answers in this case were fairly consistent and the results indicate that in this instance Port Visits are considered the best alternative for achieving the objective of Goodwill Relations.

D. COMPARISON OF MAUT & AHP METHODOLOGIES

The MAUT methodology is a well-developed technique for dealing with decision problems containing risk and encompasses utility functions that are nonlinear, such as, additive linear on each variable, multiplicative and multi-linear. Also utility functions have been shown to be more advantageous when dealing with repetitious decision-making problems. However, due to rapid changes in the utility function over time, it must be constantly reevaluated. This requires a lot of time and effort by decision-makers and does not necessarily lend itself for use as a group process.

As opposed to generating the utility function itself, the AHP methodology is useful in generating the functional values of a utility function. AHP gives scaled values that are on a ratio scale, whereas MAUT uses an interval scale. AHP provides a mechanism for checking on the consistency of the input data. As such, it is not necessary for AHP to assume consistency among the preferences. The MAUT methodology requires a transitive preference relation when building utility functions.

In recent years, several articles about the disadvantages of AHP and superiority of MAUT over AHP have been published. Dyer (1990) points out that AHP suffers rank reversal (an alternative that is chosen as the best over a set X is not chosen when some alternative, perhaps an unimportant one, is excluded from X). He concluded that changing ratio scales with interval scales as in MAUT could solve this problem. Another method for reducing the chances of rank reversal will be addressed in the next chapter. Perez (1995) gave the comparison of the two methods and stated:

> One would expect MAUT, since it requires only the construction of an interval scale, to be suitable for a wider range of applications than AHP. However, one would also expect that AHP, since it builds a ratio scale, would be more suitable to some situations in which the subjacent structure had a strong distributive component, particularly those in which the coefficients of the distribution were not strongly affected by changes in the set of available alternatives.

The other shortcoming stated by Dyer (1990) is the scaling method of AHP. The replies to these criticisms by Saaty (1990), Harker and Vargas (1990), and the corresponding counter-replies show that no consensus on scaling has been reached.

The focus of MAUT and AHP is to compare a defined set of alternatives against a value function that reflects attribute importance. Both methodologies require decision-makers to logically structure a complex problem and both appear to perform better when addressing problems with a limited number of alternatives. However, both can adequately deal with relatively large numbers of attributes. As discussed in the next chapter, both methodologies have been implemented in commercial applications, which make it easier to solve and understand AHP and MAUT related decision problems.

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IV. EXPERT CHOICE™ SOFTWARE APPLICATION AND EVALUATION

Expert Choice™ is a software application that supports decision-making by applying the concept of the analytic hierarchy process. This software package provides decision-makers with the ability to construct decision frameworks (hierarchies) from routine and non-routine decision problems. These frameworks logically organize the problem from goal to criteria to subcriteria down to the alternatives of the decision. Expert Choice™ was chosen for this analysis due to its availability, developmental maturity, problem type suitability, group applications and overall low cost.

As previously discussed, Expert Choice™, hereafter referred to as EC, is a windows-based, multi-criteria decision support software tool based on the AHP methodology. The developers of EC, Dr. Thomas L. Saaty and Dr. Ernest R. Forman, believe that AHP is a powerful and comprehensive methodology capable of accommodating the use of empirical data and subjective judgements in aiding decision-makers. The AHP methodology assists decision-makers in the decision process by allowing them to organize and evaluate the importance of various objectives and the alternative solutions of a decision. In addition to facilitating all of the aspects of AHP discussed in the previous chapter, EC allows decision-makers to do what-if or graphical sensitivity analysis. These particular features allow decision-makers to quickly evaluate the effect of a change in the importance of an objective on the alternatives of choice.

The remainder of this section will be used to describe the operation and evaluate utility of EC as an alternative selection software application. It is not the intent of this

work to recreate the user's manual, but sufficient detail drawn from that source will be provided to show how the application is utilized.

A. MODEL DEVELOPMENT

Modeling in EC can be accomplished by three methods. In the first method decision-makers can simply modify previously constructed models with similar characteristics. These models can be stored in the Model Library. Initially, the Model Library contains only the sample models that are part of the software, but it can be easily expanded as more models are completed. In the second method, decision-makers can construct the model directly using the *Evaluation and Choice* feature. In the third and final method, use of the *Structuring* feature allows decision-makers to structure a model from the "top down" or the "bottom up." *Structuring* will be discussed later in a separate section. The examples provided in this chapter use the *Evaluation and Choice* method.

The first step in the creation of a decision model is the definition of the Goal node. The Goal node is at the top level (level 0) of the model. There must be at least two or more levels below this node containing the criteria and the alternatives, but more complex models can contain several layers of criteria (subcriteria, sub-subcriteria, etc.). Figure 4.1 shows a portion of graphical user interface (GUI) window of the example *Evaluation and Choice* model screen.

Using the elements of the USPACOM decision problem, the Goal node for this example is **Select best theater engagement activity**. Goodwill, Access, and Partner are USAPCOM's three major areas of focus and represent the Criteria nodes for this goal. The Alternative nodes are contained in the next lower level and represent a sampling of

the potential alternatives that could be considered by USPACOM. The main *Evaluation and Choice* screen displays information (not shown here) in the upper right hand corner concerning the nodes. Using the currently selected node, decision-makers have instant access to information about node level, node number, global and local priority of the node, type of synthesis conducted on this node. Additionally, EC provides for the definition of each type of node up to a limit of 65 characters. The descriptions of the criteria and alternatives are provided in Appendix A.

In Figure 4.1, one can also see that the priorities for each criterion are reflected as to their relative importance to the overall goal. The EC software will only allow one to view three levels of the model at a time in this particular view. However, by using the Sideways View function, decision-makers can see the entire model, along with the priorities of each criteria, subcriteria, and alternative as it applies to the goal. The model shown in Figure 4.2 is the same as that shown in Figure 4.1, both of which have only three levels. Again, all of the priorities for each individual criteria and alternative are contained in Appendix A.

When building models, decision-makers should keep in mind the relationship of the nodes. There are parent nodes, children nodes, and other descendant nodes. A plex is a branch of the model headed by a particular node, and includes all of the descendants of that node but not the node itself. Leaves are represented by the alternatives and always placed at the bottom level of hierarchy. An exception to this applies to *Ratings* models, which will be discussed later. Lastly, peer nodes are the siblings of other nodes who have the same parent node. This will become more important later when attempting to build larger, more complex models.

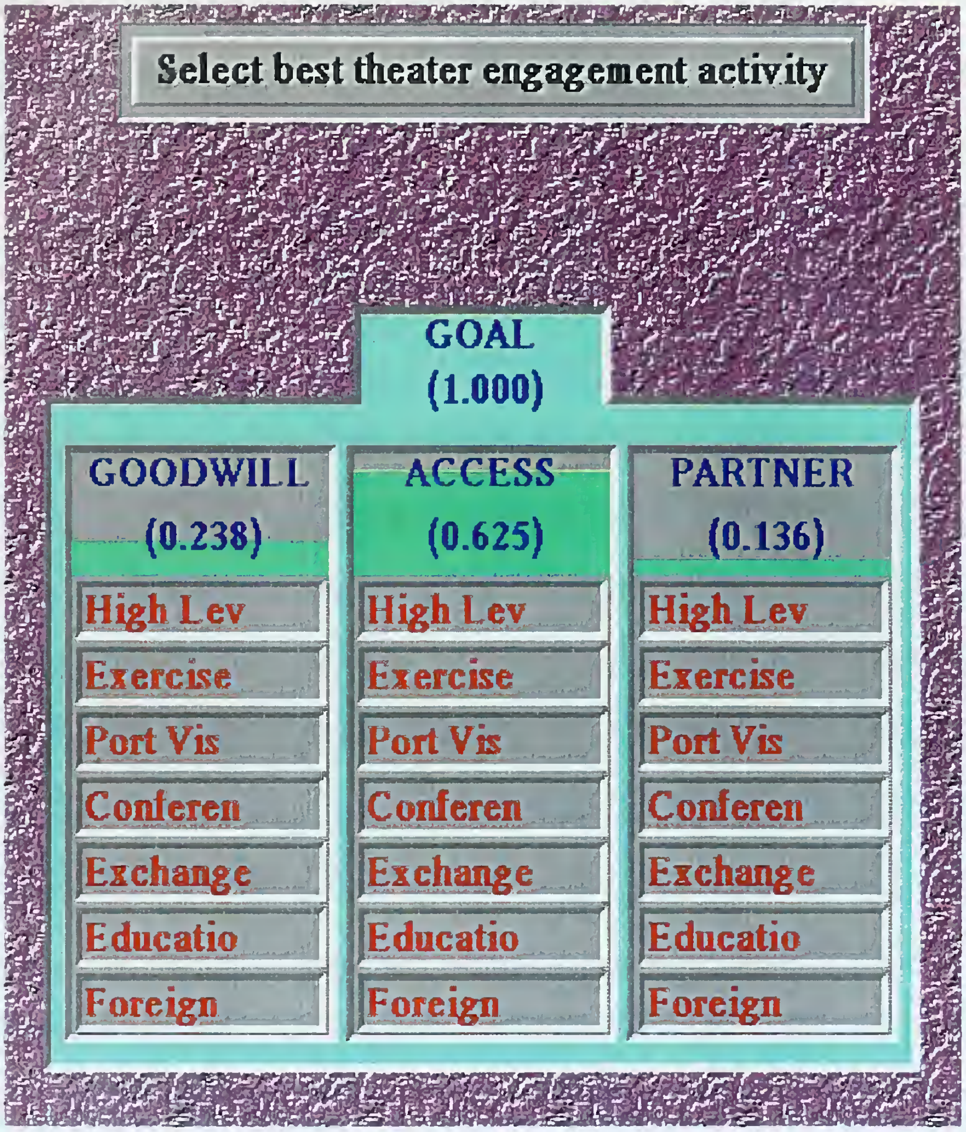

Figure 4.1 - Evaluation and Choice Model Screen.

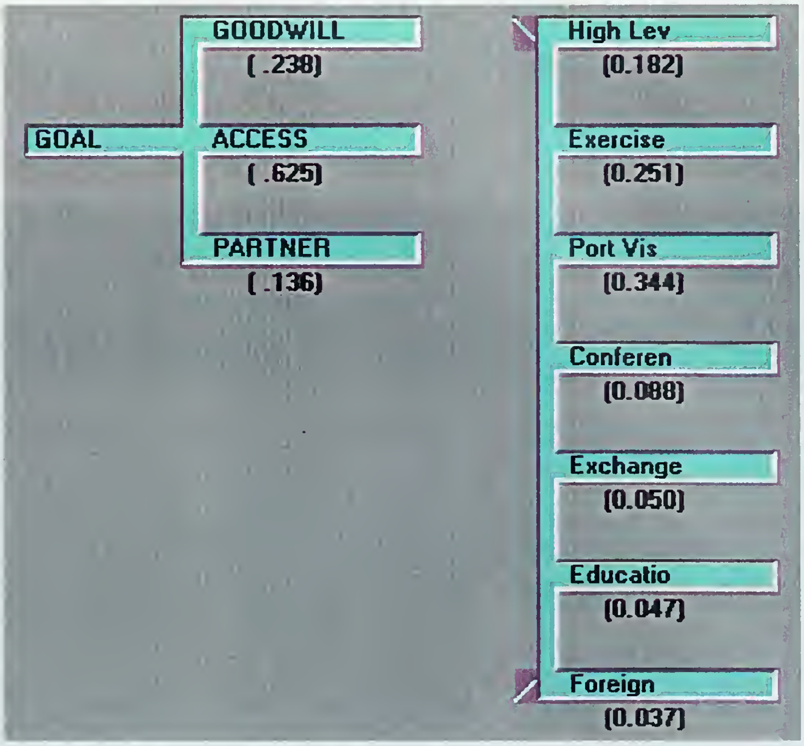

Figure 4.2 - Sideways View of Evaluation and Choice Model Screen.

Alternatives, also known as "leaves," are added to the model in the same fashion as descendent nodes. Once decision-makers have determined that all of the defined alternatives apply to any or all of the other corresponding parent nodes, it is a simple matter to copy the entire set for application to the complete model. One can either copy the current node's to its peers, copy the marked node's children to the current node, or copy the current node's children to form leaves below all other nodes at the bottom level of the model. In instances of repetitive information, EC also allows for the copying of complete plexes into other portions of the model.

In addition to these basic features, EC provides a *Notes* feature that allows decision-makers an opportunity to provide detailed descriptions of the nodes. This

feature can be utilized to provide additional information on the current node such as explaining what information was used to develop judgments concerning this particular node.

B. MODEL ASSESSMENTS

Once the hierarchy of the model has been constructed, EC provides several features to accomplish analysis of the model. The first analysis to be completed is the assessment. The Assessment Menu will allow decision-makers assess the model with pairwise comparisons, data, what-if, and ratings analysis features. In making pairwise comparisons, decision-makers have the option of selecting from three types of comparison: importance, preference, or likelihood. Additionally, the actual pairwise comparisons can be made in several forms: verbal, graphical or numerical.

Importance is normally used when comparing one criterion to another. For example, this model (Figure 4.3) indicates the Access alternative is moderately more important than the Goodwill alternative. The *Preference* method is more appropriate for comparing alternatives such as determining that Port Visits are more preferable than Conferences under the criterion Access. The *Likelihood* method is normally used when comparing uncertain events such as the probability of a combined exercise improving access.

Of the actual pairwise comparison methods, the V*erbal* comparison feature is the easiest to use and understand. This feature allows decision-makers to make comparisons of alternatives using a scale very similar to one discussed in Chapter III. As shown in Figure 4.3, this feature compares nodes using English language terms and may prove

very useful when comparing alternatives in terms of their social, psychological or political context.

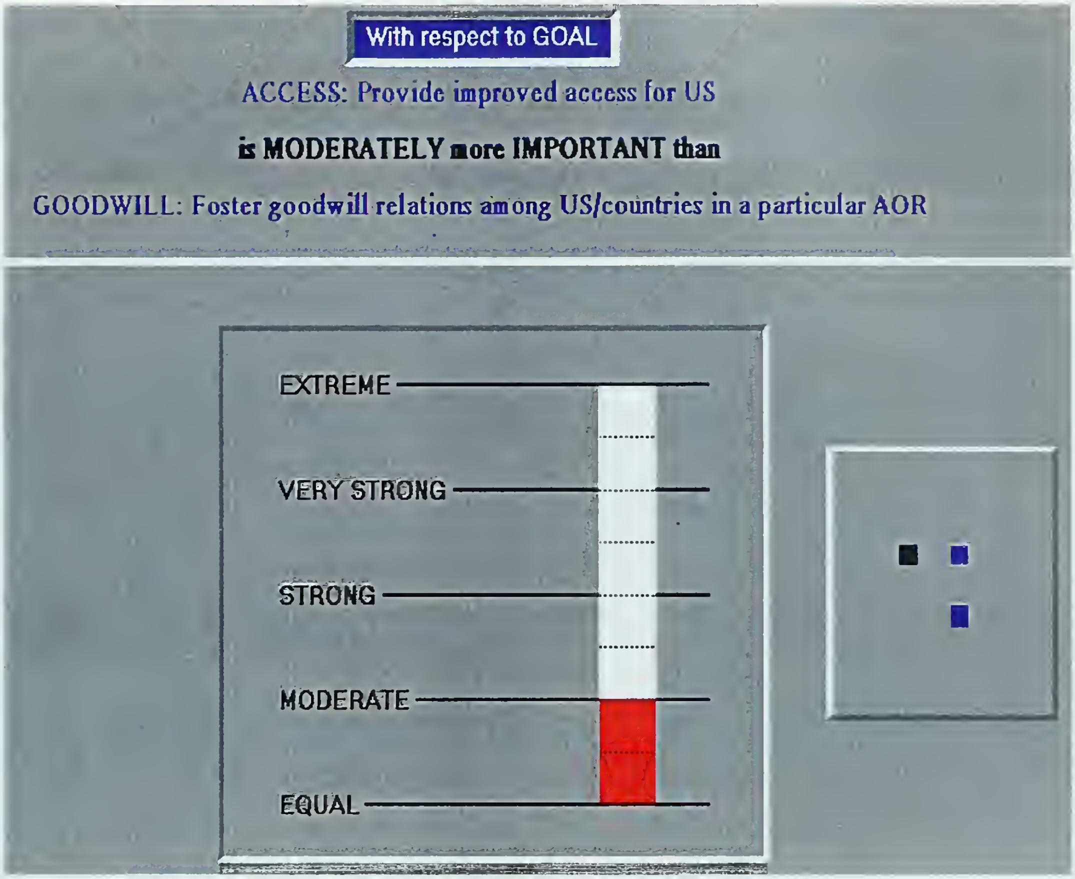

Figure 4.3 - Verbal Comparison Screen.

This type of comparison also contains a magnification feature, which allows decision-makers to make fine distinctions between two criteria that are nearly equal. This may be necessary in instances where decision-makers feel that indicating that a dominant element is twice as dominate (i.e., between Equal and Moderate) overstates the case.

The *Numerical* comparison feature may prove more useful when discussing alternatives from the context of economical or other measurable aspects. Figure 4.4 contains an example in the numerical matrix form. As one can see, this representation is not necessarily significant when dealing with individual decisions, but would possibly be better suited when dealing with group decision-making. The group-decision applications of this software will be discussed in a subsequent section.

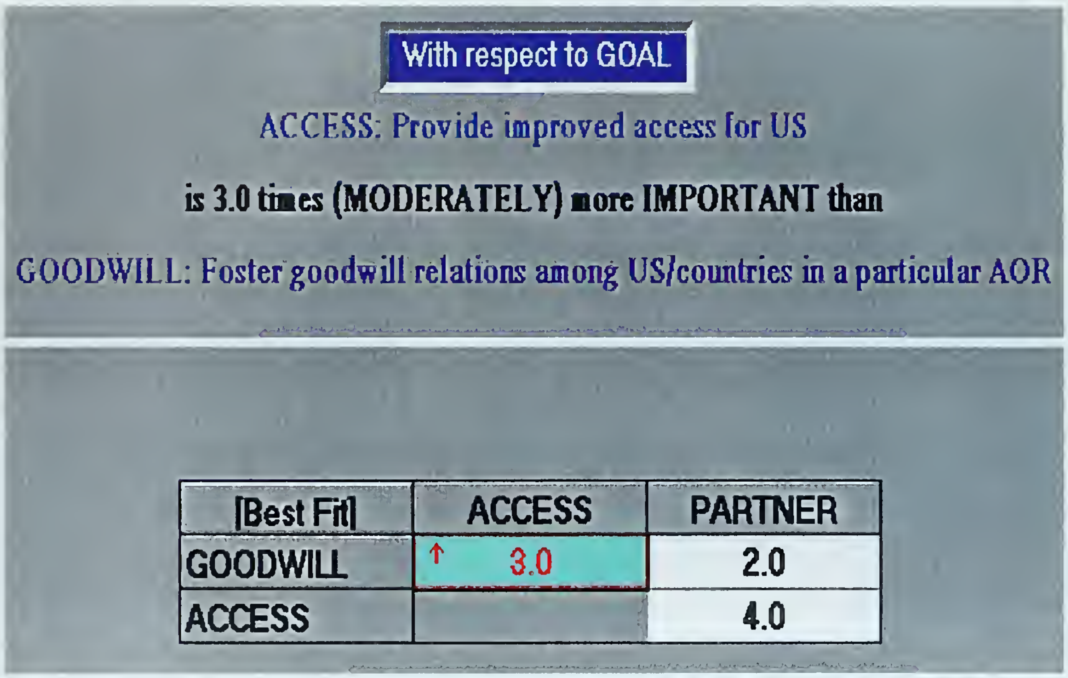

Figure 4.4 - Numerical Matrix Screen.

The information contained in Figure 4.4 is the same as that in Figure 4.3, but now decision-makers can apply a numerical value to the importance of one criterion versus another.

As shown in Figure 4.5, the *Graphical* method of comparison is somewhat more intuitive, but will require some practice by decision-makers to perfect. Using a pie chart and a bar chart, the graphical comparison method allows decision-makers to enter judgments as a visual expression of preference, importance or likelihood. This feature may prove to be useful in instances where "fuzzy" judgments need to be made and must be used in cases where there are only two factors.

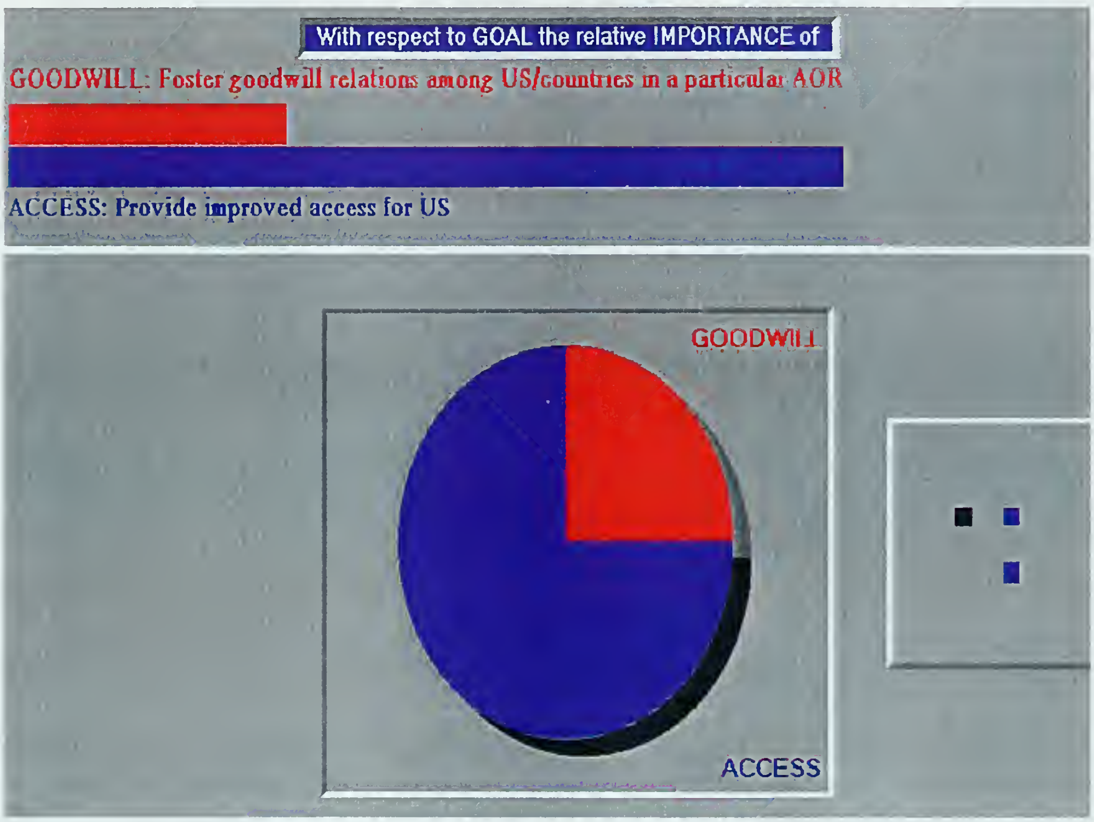

Figure 4.5 - Graphical Comparison Screen.

Another screen shown in this example is the *Preliminary Question* screen. This screen only appears when decision-makers have chosen the Verbal method of comparison and only for those comparison groups for which no judgments have yet been entered or

previous judgements have been erased. The *Preliminary Question* screen allows decision-makers to do a quick comparison of model elements by assessing whether one element is more important, equally important or less important than another. It is not necessary for decision-makers to complete the preliminary questions for every pair before moving to the *Assessment* screen in one of the comparison modes. Also, EC gives decision-makers the option of skipping the preliminary questions altogether.

Figure 4.6 - Preliminary Questions Screen.

After completing the pairwise comparison process, the next step is calculating the results of the comparison mode. Figure 4.7 shows that this calculation results in the derived priorities of the criteria with respect to the parent node.

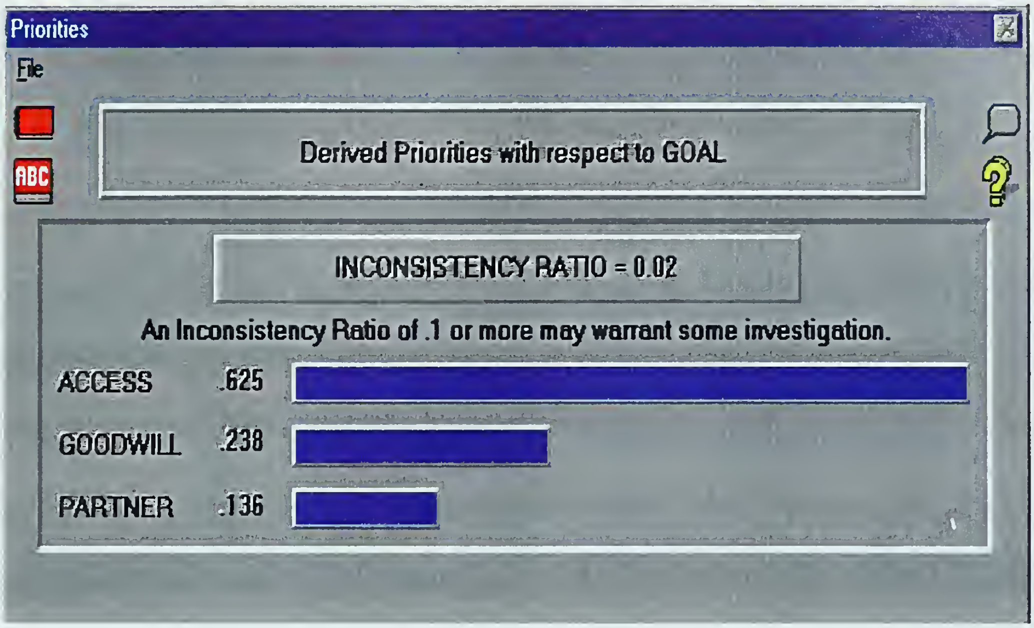

Figure 4.7 - Priorities/Inconsistency Screen.

The priorities shown in Figure 4.7 indicate that Access has much more influence than the other two criteria in obtaining the overall goal of selecting the best engagement activity. These priorities are local priorities in that they sum to one. These priorities were derived from all of the pairwise comparisons for the current group of elements.

Another source of important information shown in Figure 4.7 is the Inconsistency Ratio. As discussed in Chapter III, Saaty professes that as a general guideline, an inconsistency ratio greater than 0.10 is considered unacceptable. The results of this example indicate that it is well within the limits established by Saaty. Decision-makers

can address any inconsistencies by using the *Reorder* or *Compare* features, or they could abandon all of their previous judgments and start from scratch. The *Reorder* feature changes the order of elements in the comparison matrix according to descending priority and restarts the comparison process with the most important element first. As elements are shown in decreasing priority (left to right/top to bottom) in the Matrix mode, any judgement that appears out of order is probably the source of inconsistency. The *Compare* feature allows decision-makers to reenter the comparison mode they were previously in and then modify one or more judgments.

The next assessment method is the *Data* method. Data entry can be used to enter actual data values such as costs, probabilities, periods of time or any other values. This feature allows decision-makers to derive priorities for the nodes in comparison from the data rather than from pairwise comparisons. This method allows decision-makers to invert priorities in instances where a higher data value is less desirable than a lower value. Additionally, decision-makers have the option of converting their data entries into pairwise comparisons. The examples provided in this work do not use this method.

The *What-If* method of assessment is used to directly set the priorities using bar graphs. The nominal priority values are established by dividing each priority by the largest priority value among the group. Decision-makers have the option of changing the nominal values, the priority values or the bar lengths. As a priority value is changed, the other priority values are changed proportionally. Once decision-makers have reach a final set of values, EC can easily save these values to the individual models. Again, examples of this method will not be provided here.

The final assessment method to be discussed is the *Ratings* method. The *Ratings* method combines the hierarchy and pairwise comparison process. This method provides a format that allows decision-makers to shift the emphasis of analysis from one where alternatives are compared against each other for specific criteria to one where standards are established for the criteria and alternatives are compared against these standards. Although this method gives decision-makers the capability of analyzing a larger number of alternatives, it should only be used when decision-makers possess a thorough understanding of their criteria and will be able to generate meaningful scales for rating the criteria and subcriteria.

In contrast to the relative measurement of the *Pairwise Comparison* method, the *Ratings* method employs absolute measurement. Absolute measurement allows decision-makers to gauge elements against an established scale or set of standards instead of against each other. Using this method, decision-makers can establish prioritized evaluation categories into which engagement activities fall. An example of these ratings scales could evaluate the engagement activity's impact on the overall goal if implemented such as Excellent, Above Average, Average, Below Average, Poor. Another scale could evaluate the engagement activity's priority with respect to the overall goal such as Extremely Critical, Highly Critical, Moderately Critical, Not Critical and/or Extremely Significant, Very Significant, Moderately Significant, Somewhat significant, Not Significant. A third example could evaluate the engagement activity's risk such as High Risk, Significant Risk, moderate Risk, Low Risk. These ratings scales or any others devised by decision-makers can serve to indicate the influence of a particular alternative

engagement activity on the achievement of the overall goal.

Although the criteria still undergo pairwise comparisons, the alternatives are compared against this previously established scale. One potential advantage of using the *Ratings* method is the inclusion of the *Benefits/Costs Analysis* feature. This feature of EC gives decision-makers a quick, simple and straightforward method for optimizing resource allocation decisions.

C. SYNTHESIZING JUDGMENTS

Now that the various assessment methods have been discussed, the next process concerns the synthesizing of the judgments. Synthesizing is the process of weighting and combining priorities throughout the model after all of the judgments are made to yield the final result. Synthesis determines the global weights of the model's nodes by multiplying each node's local priority by its parent's weight. These global weights are then summed to yield the overall weights. As discussed in Chapter III, the alternative with highest weight is the most preferred alternative.

The *Synthesis* process allows decision-makers to display their results in summary or detail form. The summary form is shown in Figure 4.8 and indicates that Port Visits alternative is the most preferred engagement activity for this example. The detailed form of this example is contained in Appendix A. Decision-makers are also given the option of displaying their results in the Ideal or Distributive mode. This process does not apply to Ratings models as the overall weight of an alternative is obtained from the total score column of the spreadsheet.

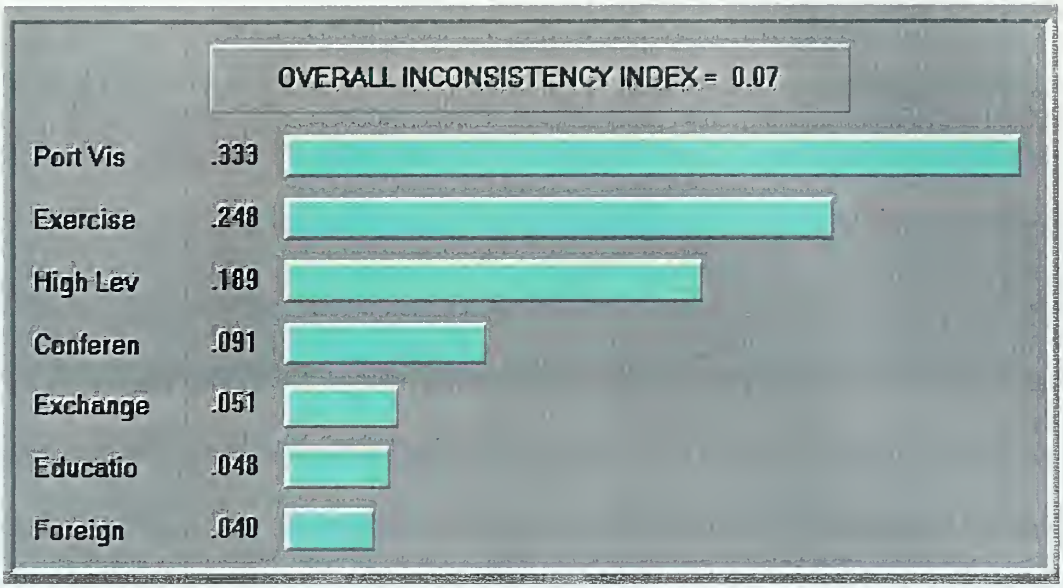

Figure 4.8 - Synthesis Summary Results Screen.

The Ideal mode is useful when comparing several alternatives that are very similar to each other. This gives decision-makers the ability to prevent the weight of the best alternative from being diluted by its competitors. Instead of using normalization, the Ideal mode divides the numerical ranks of the alternatives for each criterion by the largest value among them. The most preferred alternative receives a value of one. When new alternatives are added, they are only compared with the most preferred alternative for that particular criterion.

The Distributive mode is useful in instances where the choice of the best alternative is influenced how many other alternatives exist and what those other alternatives actually are. The Distributive mode distributes the weights of the criteria among the alternatives, a process that proportionally divides the full criteria weights in a manner relative to the percentage of the preference of the alternatives. Discussion of this

mode brings up the topic of rank reversal.

According to the developers of EC, rank reversal of the final alternatives is only possible in the Distributive mode and usually occurs when other alternatives or added or deleted. When using relative measurement to rank alternatives, decision-makers must realize what happens to one alternative also affects all of the other alternatives contained in the hierarchy. Inserting an additional alternative that bears a close resemblance to one or more alternatives already under consideration essentially spreads the overall priority of that particular between both of those alternatives instead of just one. When an alternative is introduced that is a duplicate or a close copy of an existing alternative, with respect to the established criteria, decision-makers should revise the entire set of criteria or delete that particular alternative. Since the derive priorities of criteria and alternatives are specifically tailored for that particular decision problem, any change (adding new criteria or alternatives, deleting or changing others) essentially changes the problem and makes it a new one. A new problem that must be considered separately from the decision problem that previously existed. (Golden, et al, 1989)

In either case, the results of the Distributive or Ideal method are often very similar to each other. The developers believe that the choice of synthesis methods depend on whether the goal is to select the single best alternative (Ideal/open system) or prioritize all of the alternatives (Distributive/closed system).

D. SENSITIVITY ANALYSIS

Sensitivity analysis can be used by decision-makers to investigate the sensitivity of the alternatives to changes in the priorities of the criteria. Starting from the Goal node,

sensitivity analysis shows the sensitivity of the alternatives with respect to the criteria immediately below the goal. This allows decision-makers to observe how the overall priorities of the alternatives change as the priorities of the criteria are changed. This analysis can be performed at lower levels of the hierarchy in models that possess more than three levels.

The Sensitivity Analysis mode provides decision-makers with five graphical options, each of which emphasizes different aspects of the priorities of the criteria and alternatives. These five options include Performance, Dynamic, Gradient, 2D Plot, and Difference sensitivity analysis. There are two important considerations to remember when conducting sensitivity analysis. First, any changes in graphical mode are immediately reflected in the other modes. Second, the sensitivity analysis graphs will be depicted differently depending on whether the type of synthesis mode is Ideal or Distributive.

The Performance sensitivity graph depicts all of the information about how the alternatives behave with respect to each criterion and provides the most compact presentation. The Performance sensitivity graph also shows a composite sensitivity presentation of each alternative's overall performance. As shown in Figure 4.9, a vertical line represents each of the three criteria in this example. As read from the right axis, the point where the alternative line intersects the particular vertical criterion line represents the priority received by an alternative, with respect to that criterion. The overall priority of the alternative is represented by its intersection with the last vertical line, which is labeled Overall.

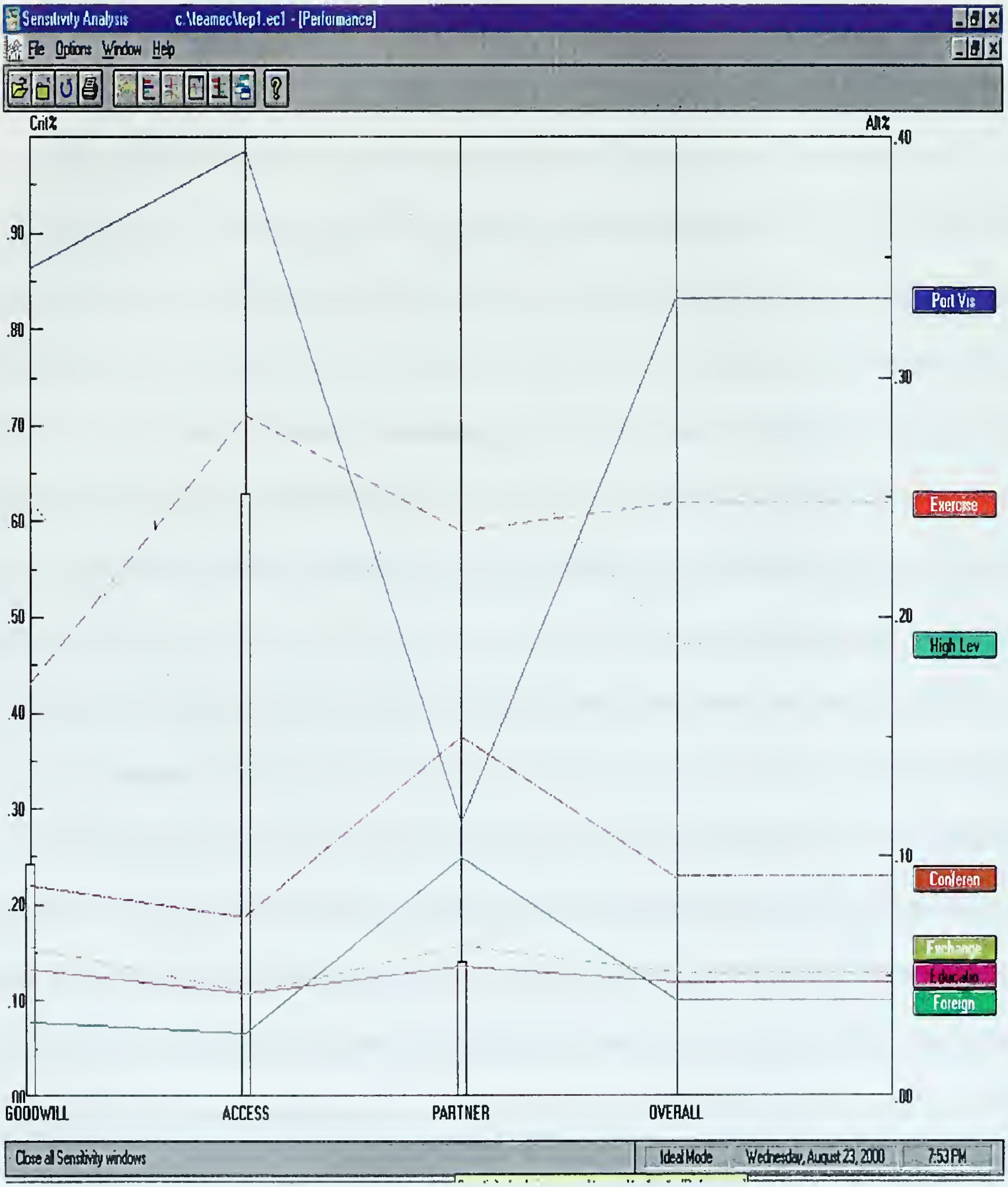

Figure 4.9 - Initial Performance Sensitivity Analysis Screen.

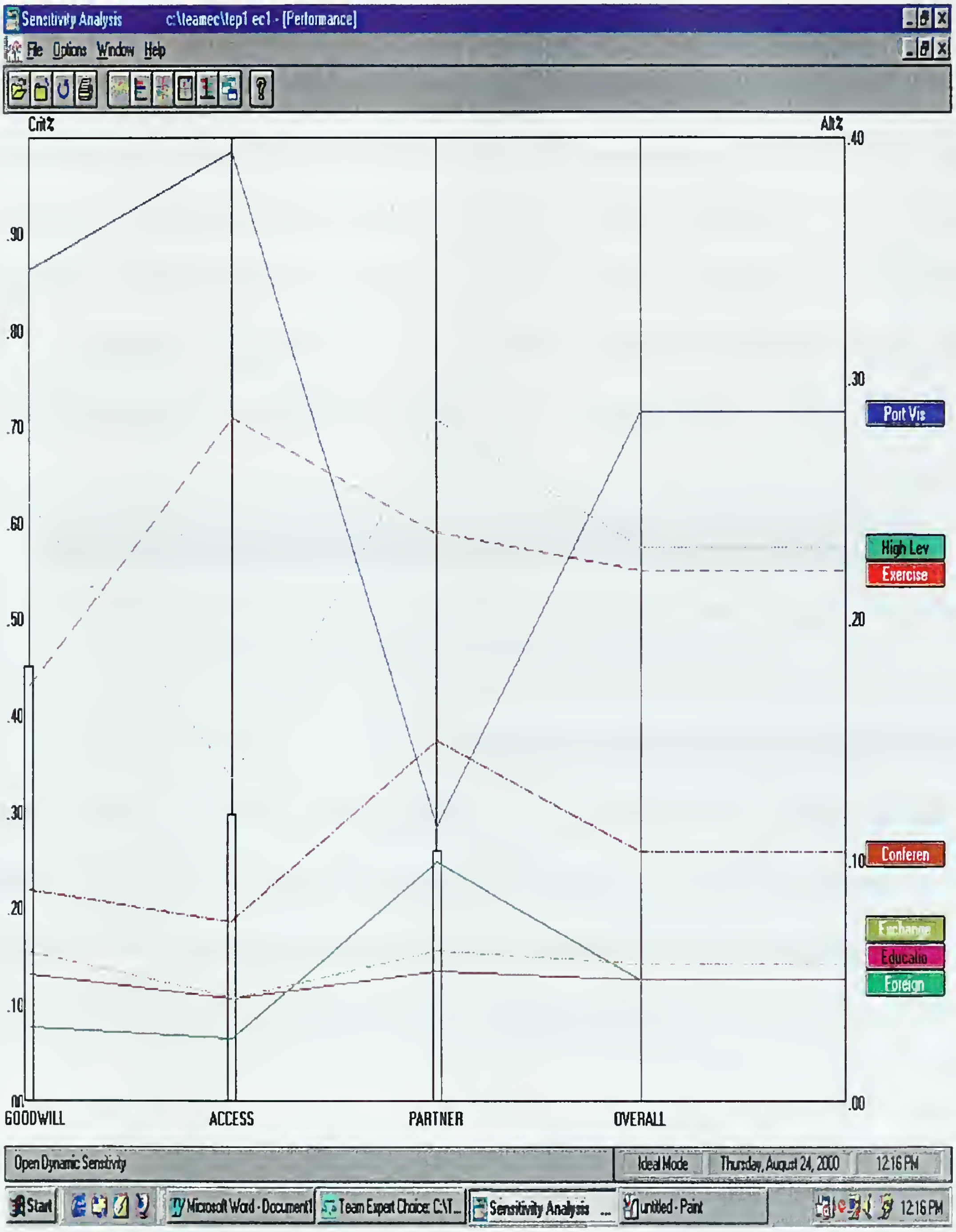

Figure 4.10 - Performance Sensitivity Analysis Screen with Changes.

In this example, the sensitivity analysis is done using the Ideal synthesis mode. The results depicted in Figure 4.9 are consistent with previous examples discussed in this chapter. The Access criterion still has the greatest influence of the three criteria and the Port Visits alternative still represents the best alternative. The results depicted in Figure 4.10 show what occurs when decision-makers change the influence of one of the criterion. In this case the influence of the Access criterion was reduced to approximately 0.300 vice 0.625 while the influence of the Goodwill and Partner criteria were increased proportionally. As the results indicate, the overall influence of the Port Visits alternative is reduced and the High Level Visits alternative becomes more significant than the Exercises alternative. The changes to the other alternatives appear to be insignificant in this case.

The Dynamic sensitivity graph is the next method for performing sensitivity analysis. This graph shown in Figure 4.11, places its emphasis on the priorities of the criteria in the model and shows decision-makers how changing the priority of one criterion affects the priorities of the alternatives.

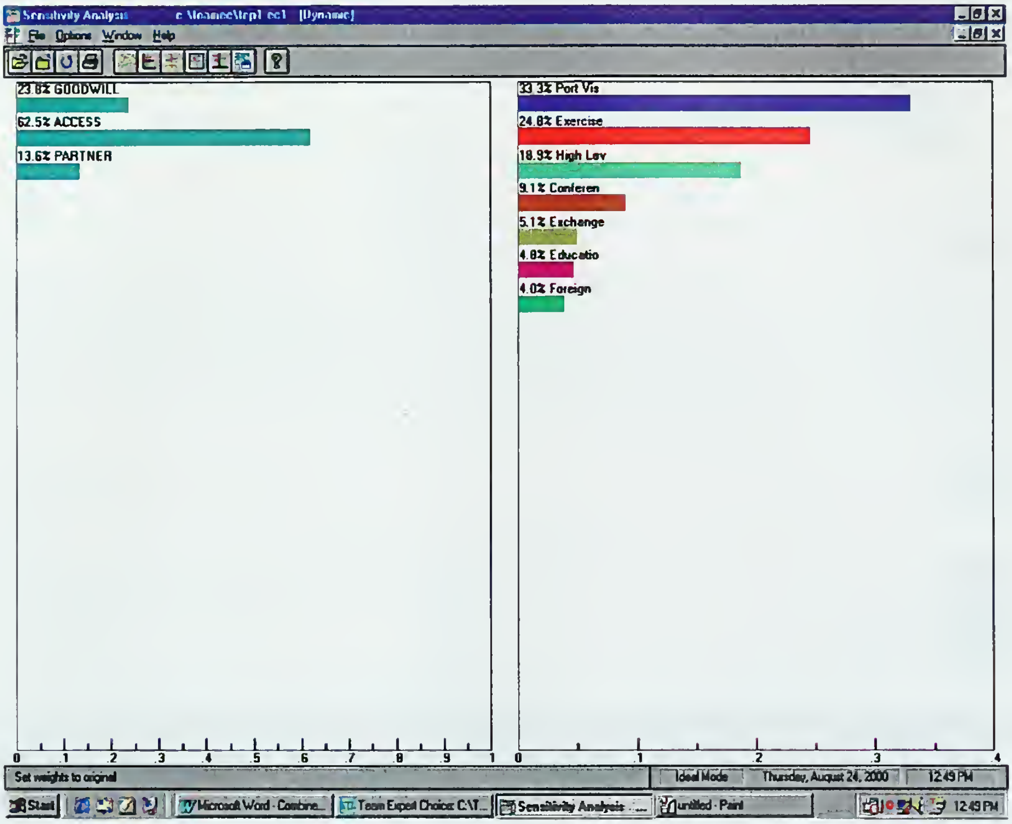

Figure 4.11 - Dynamic Sensitivity Analysis Screen.

As shown in Figure 4.12, this sensitivity graph also allows decision-makers to look at the influence of the individual criterion on each alternative by displaying their components. Decision-makers can examine the influence of a criterion by simply dragging the bar to the right and observing how the priorities of the remaining criteria are decreased proportionally with respect to their original priorities.

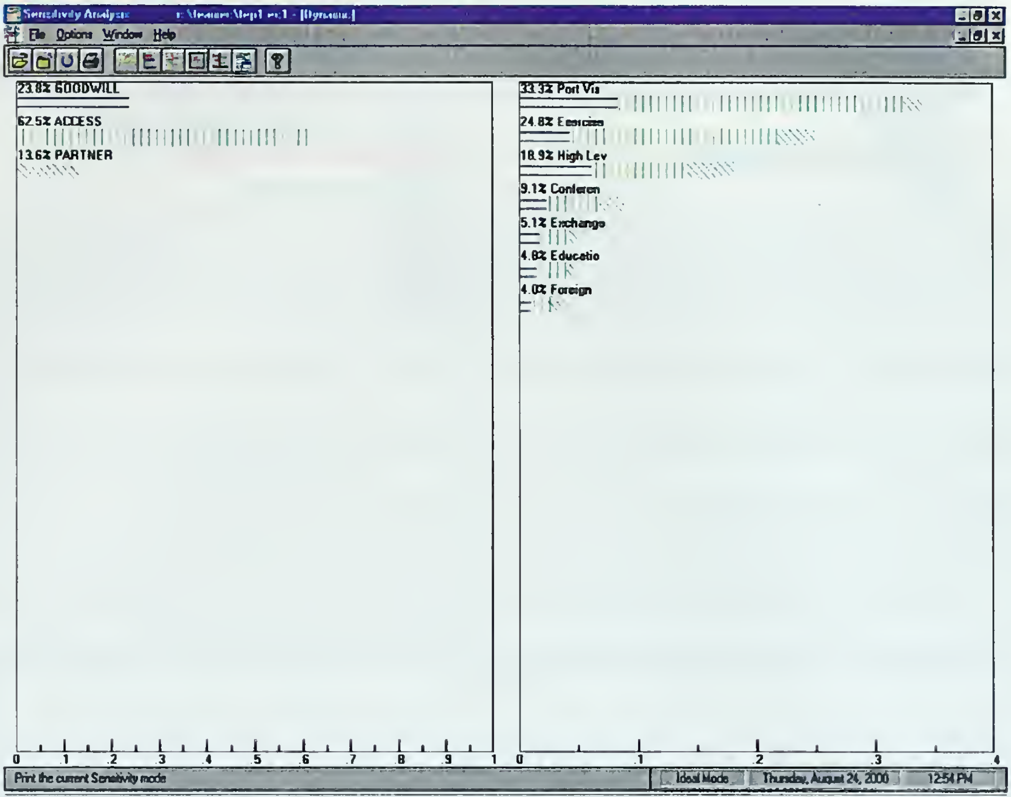

Figure 4.12 - Dynamic Sensitivity Analysis Screen with Components.

The Gradient sensitivity graph provides a linear representation of the alternatives against a single criterion. This sensitivity graph provides an emphasis on how the alternatives relate for any priority assigned to the criterion shown on the x-axis. The gradient sensitivity analysis lies in the points where the lines of the alternatives intersect with each other. This type of analysis gives decision-makers the capability to identify the "trade-off" points where the preferred alternative with respect to a selected criterion changes. Figure 4.13 provides an example of this analysis using the Access criterion.

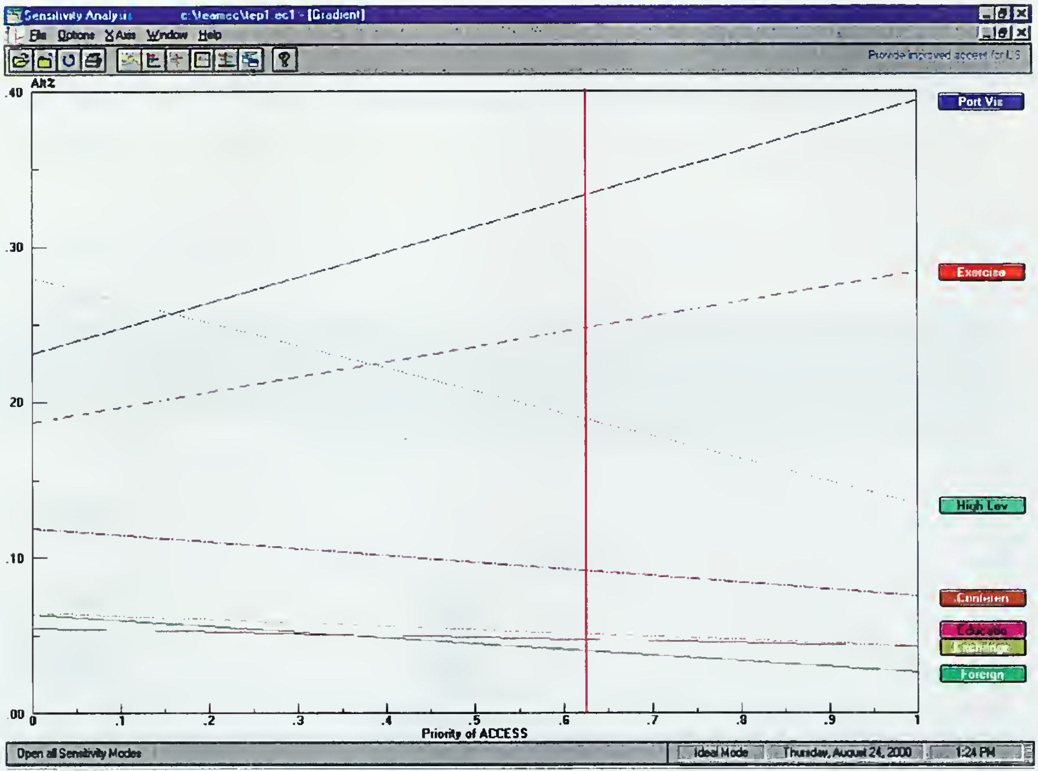

Figure 4.13 - Gradient Sensitivity Analysis Screen.

The 2D Plot sensitivity graph shows how well the alternatives perform with respect to any two criteria. The graph is divided into quadrants with each of the particular criterion being represented by the x- and y-axis. As shown in Figure 4.14, the most favorable alternatives as defined in the model will be depicted in the upper right quadrant, while the least favorable alternatives will be depicted in the lower left quadrant. The closer the alternatives are to the corners (upper right – best, lower left – worst), the more significant their impact. Alternatives depicted in the upper left and lower right indicate potential conflicts between the two criteria and decision-makers may need to conduct some trade-offs. Figure 4.14 indicates that an opportunity for trade-offs between the Exercises alternative and the High Level Visits alternative may exist.

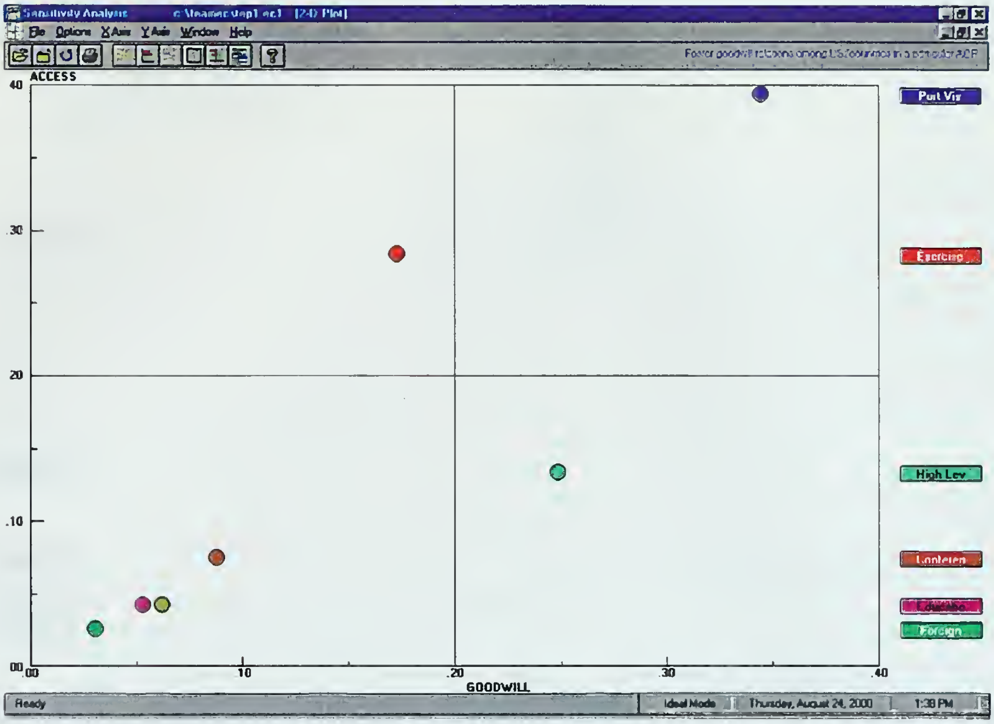

Figure 4.14 - 2D Plot Sensitivity Analysis Screen.

The last sensitivity graph to be discussed is the Differences sensitivity graph. In this sensitivity analysis method, one alternative is fixed for comparison against any of the other alternatives. This allows decision-makers to compare criteria to see which criterion accounts for the prioritization of the alternatives. The fixed alternative is depicted on the left side of the graph. Alternatives for comparison against the fixed alternative can be cycled through using the tabs above the graph. Looking at Figure 4.15, the bar extends to the left if the alternative on the left is the best on that criterion and to the right if the alternative on the right is the best. This particular example depicts the differences between the Port Visits alternative and the Exercises alternative. The results contained

in Figure 14.5 show that the Port Visits alternative performs better than the Exercises alternative under the Goodwill and Access criteria, but performs worse than the Exercise alternative under the Partner criterion. Graphs of the remaining comparisons are contained in Appendix A.

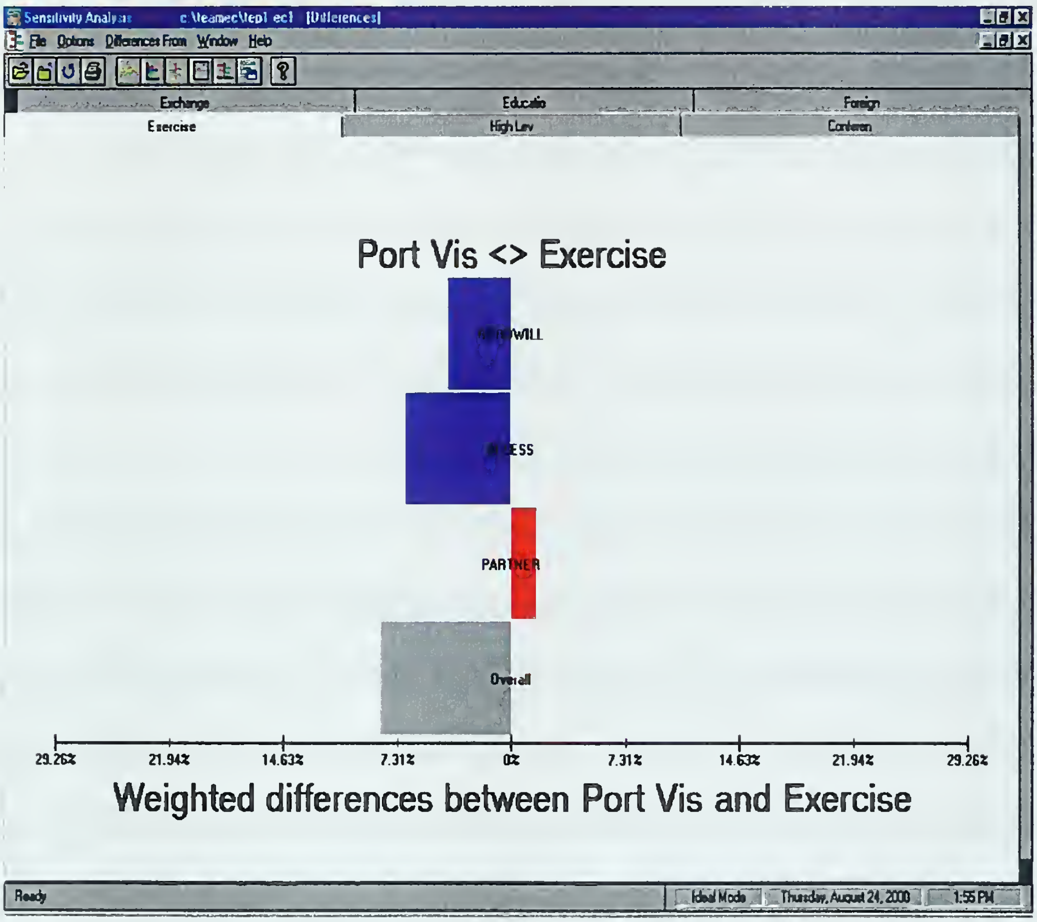

Figure 14.5 - Differences Sensitivity Analysis Screen.

E. GROUP APPLICATIONS

1. Group Decision Making

Group decision-making by its very nature is a somewhat contentious process, but it is also one that can offer some unique benefits and trade-offs. The group decision-

making process provides an environment for the presentation and analysis of diverse perspectives from multiple sources. In addition to presenting the opportunity for the discussion of new ideas that previously may not have received consideration, group decision-making can sometimes lead to a more widespread acceptance of a decision within an organization. Herein lies the value of a decision support tool such as Expert Choice™. When employed in a group setting, this software application provides a valuable tool for building consensus among the participants. One drawback to this approach is that there may disagreements between participants and consensus may be difficult to reach. However, it should be noted that group consensus may be difficult to reach no matter what tools, procedures, or processes are used. Reaching consensus should be a goal, not a requirement. (Expert Choice, 1998)

Expert Choice™ addresses this issue by including all inputs, from each group member, in the model during each step of the decision-making process. Also included is the designation of importance, which is determined by the group, not the individual. In the group decision-making environment, "factors such as personal charisma, perceived intelligence and expertise, and size and strength of an outside constituency can make some participants...'more powerful' than others (Golden, et al, 1989)." Instead of relegating themselves to playing a lesser role in the decision-making process, EC manages the variability of each individual's knowledge by allowing the group to prioritize the relative importance of each decision-maker in the decision-making process. (Expert Choice, 1998) Even in military organizations where formal ranks are known and

relative power is easy to assess, "these weights can be used to emphasize judgmental contributions or to increase voting power (Golden, et al, 1989)."

The EC software application breaks down the group decision-making process in three activities, *Brainstorming, Structuring*, and *Evaluation and Choice.* Decision-makers use the *Brainstorming* activity to make lists of issues, objectives, and alternatives. Staff members can vote on items contained in the list to determine their relevance to the decision problem being considered. The results of this activity provide the starting point of the *Structuring* activity. The *Structuring* activity can be used to group objectives and sub-objectives into a format that allows the decision model to be readily generated. The results of this activity provide the starting point of the *Evaluation and Choice* activity. In the *Evaluation and Choice* activity group members use the process of comparison to indicate their perceptions on the relative importance of each objective, sub-objective and alternative. As previously discussed, these comparisons are used to derive the weights of the objectives and alternatives, which are then synthesized to provide the results. Further analysis of the impact of each element upon the overall decision can be conducted through graphical sensitivity features discussed in the previous section. The decision model can be completed by using these activities in sequence or can be built directly in the ***Evaluation and Choice*** activity. The decision model examples provided in this chapter were constructed using the latter method. (Expert Choice, 1998)

2. Questionnaire and Brainstorming

This application is a separate feature offered by the developers of Expert Choice™ is not included as part of the basic or group software systems. However, it is a

very useful tool when decision-makers are attempting to model complex decision problems in a group environment. As stated in the previous section, the *Brainstorming* activity is used to create a list of issues, objectives or alternatives. Generally, the items on these lists are related to each other in some fashion. An important concept in using this technique is get as many ideas on table as possible before the evaluation and prioritization process begins. The *Questionnaire* activity is designed to allow group members to provide their input on specific questions. These questions may be independent of each other and may be designed to acquire information on a varied and unrelated range of issues. Although these two activities are designed to work independently of each other, carefully designed questions in the *Questionnaire* activity can enhance the results of the *Brainstorming* activity. (Expert Choice, 1998)

According to the developers of EC, the *Brainstorming* activity is a capability that provides a highly effective method for obtaining expert opinions about a particular problem and determining the initial direction of attack. This format allows group members the opportunity to consider a wide variety of ideas that may not have normally been considered. As opposed to the traditional use of brainstorming to develop creative ideas, EC's concept of brainstorming is intended to get all of the potential issues out in the open without attempting to determine their level of significance. (Expert Choice, 1998)

The *Brainstorming* activity allows the group members to list all of the potential items or issues individually or they may be categorized according to some particular characteristic. At this stage, decision-makers can use the voting feature of EC to pare

down the list of issues or categories to a more manageable level. This feature may also serve to indicate the initial popularity of certain items or issues. It must be noted that the voting conducted by group members at this stage is only intended to screen the list of potential issues and objectives before completing the model. Actual evaluation of the model will be completed in the *Evaluation and Choice* activity after the model is fully constructed. (Expert Choice, 1998)

This activity allows members of the group to vote in four different ways depending on how the issues or objectives are defined. In the first method, each participating member of the group rates each item on a scale of 1 - 10 (10 - most important, 1 - least important, 0 - not voting). The next method of voting involves a simple indication of yes or no. The third method allocates a specific number of total votes for each participating member of the group. Any number of these votes may be cast for any of the items or issues under consideration. However, once group members have used all of their allocated votes, they may not vote on any remaining items. For instance, if a group member is allocated 10 votes and uses all of them on the first two items, then he or she cannot vote on the rest of the items being considered. The last method of voting consists of determining a particular number of items that each group member may be allowed to vote on. For example, each participating member is only allowed to vote 4 items. Once all four votes have been cast, this member is not allowed to vote for any remaining items. To ensure consistency in the results, once a voting method has been selected, this method should be used for voting on all of the items.

Once complete, the voting results are averaged for presentation. This method can also be used to prioritize or reduce a larger list of alternatives. (Expert Choice, 1998)

The *Questionnaire* activity is similar to the *Brainstorming* activity in that group members vote on the questions under consideration. However, the *Questionnaire* activity provides for the consideration of a greater variety of ideas because it does not require that members of the group used the same voting method for each question. Although this particular feature provides for greater flexibility when developing potential questions, it will not allow the group to make direct comparison of votes on each of the questions being considered. (Expert Choice, 1998)

The are six methods of voting included in the *Questionnaire* activity. The first two methods, Rating on a scale of 1-10 and yes/no are exactly like those methods contained in the *Brainstorming* activity. The third and fourth methods consist of selecting from a list of multiple choices. The third method contains a list of choices indicated from A-E, and the fourth method lists multiple choices numbered from 1-10. The fifth and sixth methods are similar to the third and fourth methods in that these methods consist of choosing from a list of multiple choices. However, in these two methods, each choice (A-E and 1-10, respectively) is assigned a weight that has been developed and designated by group consensus. The final results of these last two methods are the average of the weights of the selected choices. (Expert Choice, 1998)

Again, the results of either or both of the *Brainstorming* and *Questionnaire* activities can provide the starting point of the *Structuring* activity.

3. Structuring

In the group decision-making process, the *Structuring* activity allows decision-makers to begin the analysis of a decision problem in two different ways. The first method uses the alternatives or objectives generated through the use of the *Brainstorming* and *Questionnaire* activities. These alternatives of choice are exported directly into the *Structuring* activity for further analysis. The second method consists of entering key concepts and ideas into the Structuring "blackboard" as they are presented and discussed by the group. From here, these ideas and concepts can be organized by elements and assembled into a hierarchical model and exported to the *Evaluation and Choice* activity for evaluation. (Expert Choice, 1998)

If the listing of alternatives method is chosen, the next process involves the identification of each alternative's pros and cons. These advantages and disadvantages will be translated and converted into objectives and sub-objectives or criteria and sub-criteria. The developers of EC believe that, in order to derive the objectives from the pros and cons, decision-makers must reconceptionalize pros and cons in value-neutral terms (instead of positive/negative terms) and specify them in a general form. It is the decision-maker who mentally converts the advantages and disadvantages of an issue into objectives. Decision-makers must determine and evaluate what each alternative's advantages and disadvantages means in terms of the organization's overall goals and objectives. Expert Choice™ can then be used to automate the process of determining what important objectives need to be met in order to resolve the issue.

The *Structuring* activity also allows decision-makers in a group environment to start the construction of their decision models from the top down or the bottom up. Constructing the model from the bottom up begins with the identification of alternatives at the bottom and progressing upward toward the overall goal. This method of model construction is best suited for those instances where decision-makers understand the alternatives better than the objectives. As previously discussed, determining the pros and cons of the alternatives may aid in the definition of the objectives. Once the objectives are categorized, they can be evaluated by the Evaluation and Choice activity. (Expert Choice, 1998)

In instances of strategic planning where the objectives are better understood than the alternatives, top down structuring can be used. Again, the resulting hierarchy of objectives, sub-objectives, and alternatives can be evaluated by the Evaluation and Choice activity. (Expert Choice, 1998)

F. SYSTEM/TRAINING COSTS

Single user versions of the current release of Expert Choice™ Professional is relatively inexpensive at $1195.00. However, the Team Expert Choice™ 25-user bundle packages, which include Team Keypad, (group hardware and software), Internet/Network license, 25 participant licenses, 2 builders licenses, 1 year technical support and a three-day training seminar are somewhat more expensive at $29,995.00. The radio frequency keypad hardware used for group environments to facilitate the remote input of individual participants is available separately from numerous other sources. Expert Choice, Inc. offers a basic set-up consisting of 10 keypads and 1 radio frequency receiver for

$4730.00. Extra keypads are available at the price of $285.00 each. Additionally, the Questionnaire & Brainstorming Keypad software application is available separately for the cost of $4995.00. Lastly, the three-day training seminar ($1495.00 per person) provides instruction on the use of the group software application, including all of the topics covered in this chapter and use of the remote keypad technology. In an effort to reduce overall training costs, this seminar could serve as a "train the trainer" function where only a few individuals would need to actually the attend. After completion of the seminar, they would then serve as organizational instructors for implementation of system.

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V. CONCLUSIONS

The two types of decision support methodologies represented in this work represent a portion of the current state of management science's efforts to assist decision-makers in solving multicriteria decision problems. Both of these methodologies are well founded, in theory and in practice, and have existed for over 25 years. These decision support methodologies and their software applications, like all other decision support tools, are neither designed to replace the decision-maker nor diminish the responsibility for the decision made. Both of them are capable of representing a non-trivial decision process in an effort to expand the rational boundaries of those involved in the decision-making process. These and other decision support tools only serve to assist in an analysis of as much of the available information as the decision-maker desires.

This decision support tool can be used by USPACOM to more effectively and efficiently conduct the various and multiple levels of the coordination, interaction, and decision making currently required by the 35 separate internal and external staff and support entities during the course of the Engagement Working Groups. Models developed by the individual country chapters can be imported and evaluated as a global model with respect to the CINC's overall goal. Once individual country models are developed and properly analyzed with respect to the appropriate priorities and weights, this tool can serve as a method for quantifying the impact of the most significant engagement activity. Additionally this decision support tool can be useful in

comparatively assessing the value of one activity type versus another in the achievement of a particular goal or objective.

As one can observe from the previous chapter, the EC software application provides a simple, intuitive, user-friendly method for aiding decision-makers in the selection of alternatives. Expert Choice™ supports decision-making by applying the concept of the analytic hierarchy process and provides decision-makers with the ability to construct decision frameworks (hierarchies) from routine and non-routine decision problems. These frameworks logically organize the problem from goal to criteria to subcriteria down to the alternatives of the decision. Although the examples provided here are simplistic in nature, it is easy to visualize the power of this tool if the models were populated with more detailed information concerning the overall goal, criteria and alternatives.

Although this decision support tool, or any other currently available tool, does not completely address USPACOM's requirement to assess the effectiveness of engagement activities proposed, planned and conducted within its AOR, Expert Choice™ does provide a means for quantifying subjective judgments and assisting in the decision process. Alone, Expert Choice™ provides a powerful analytic tool for developing and narrowing down a complex and lengthy list of potential alternatives and ultimately selecting the best alternative with respect to the established criteria. Combined with Situational Influence Assessment Modeling (SIAM) or other influence modeling tools, Expert Choice™ should be capable of providing actual measures of effectiveness for individual theater engagement activities and overall theater engagement plans.

In this era of reduced budgets and closer scrutiny of how these scarce resources are utilized, the Cost/Benefit analysis feature of Expert Choice™ can be used by decision-makers and planners to analyze and maximize current resource allocations. Additionally, the use of Expert Choice™, along with the development and implementation of USPACOM's Theater Engagement Plan Management Information System (TEPMIS), will provide a mechanism for comparing planned-versus-executed engagement activities and the comparative value assessment of one activity versus another in the achievement of goals and objectives.

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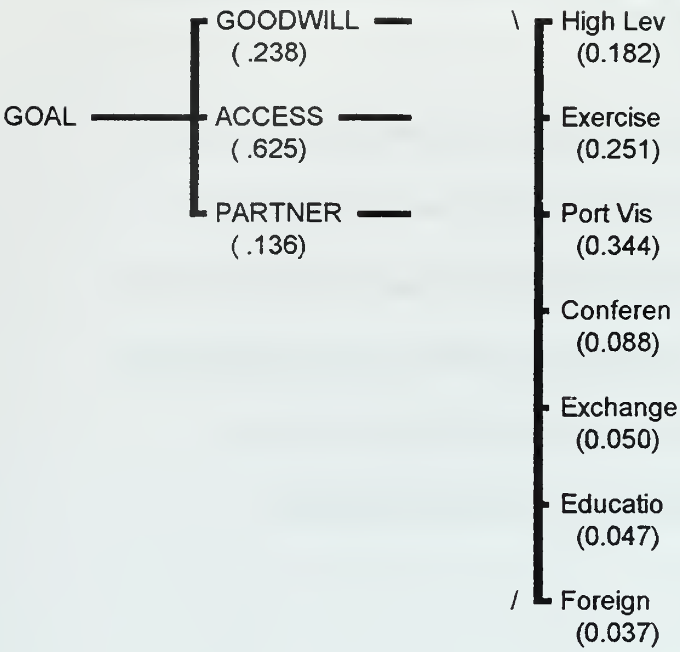
APPENDIX A: EXPERT CHOICE (AHP) SYSTEM OUTPUTS AND GRAPHS

The following diagrams represent the full, printable versions of the GUI screens contained in Section B of Chapter IV. These graphs and diagrams also include: the overall model hierarchy; numerical, matrix, graphic, and questionnaire views of all of the criteria and alternatives and their respective comparisons; synthesis of the leaf nodes with respect to the overall goal (ideal and distributive); and the graph outputs for the performance, dynamic, gradient, 2-D plot, and differences sensitivity analysis.

Select best theater engagement activity



Abbreviation	Definition
GOAL	
ACCESS	Provide improved access for US
Conferen	Information exchange conferences concerning regional issues
Educatio	Resident attendance of joint/service/military war/staff colleges
Exchange	Exhange of senior/mid-level military officers for joint billets
Exercise	Conduct of joint/combined military training exercises
Foreign	Foreign military sales of excess military equipment
GOODWILL	Foster goodwill relations among US/countries in a particular AOR
High Lev	Visits/Talks between high level civilians and/or senior military
PARTNER	Develop coalition partner in a particular AOR
Port Vis	Port Visit in AOR conducted by ARG, CBG, or single ship

OVERALL HIERARCHY VIEW

Select best theater engagement activity

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

	ACCESS	PARTNER
GOODWILL	(3.0)	2.0
ACCESS		4.0

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Select best theater engagement activity
GOODWILL	Foster goodwill relations among US/countries in a particular AOR
ACCESS	Provide improved access for US
PARTNER	Develop coalition partner in a particular AOR

CRITERION MATRIX VIEW

Select best theater engagement activity

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	GOODWILL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	ACCESS
2	GOODWILL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PARTNER
3	ACCESS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PARTNER

Abbreviation	Definition
Goal	Select best theater engagement activity
GOODWILL	Foster goodwill relations among US/countries in a particular AOR
ACCESS	Provide improved access for US
PARTNER	Develop coalition partner in a particular AOR

CRITERION QUESTIONNAIRE VIEW

Select best theater engagement activity

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1	GOODWILL	ACCESS
2	GOODWILL	PARTNER
3	ACCESS	PARTNER

Abbreviation	Definition
Goal	Select best theater engagement activity
GOODWILL	Foster goodwill relations among US/countries in a particular AOR
ACCESS	Provide improved access for US
PARTNER	Develop coalition partner in a particular AOR

CRITERION GRAPHICAL VIEW

Select best theater engagement activity

Node: 10000

Compare the relative PREFERENCE with respect to: GOODWILL < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exercise
2	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Port Vis
3	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
4	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
5	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
6	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
7	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Port Vis
8	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
9	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
10	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
11	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
12	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
13	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
14	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
15	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
16	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
17	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
18	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
19	Exchange	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
20	Exchange	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
21	Educatio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign

Abbreviation	Definition
Goal	Select best theater engagement activity
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High Lev	Visits/Talks between high level civilians and/or senior military
Exercise	Conduct of joint/combined military training exercises
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Conferen	Information exchange conferences concerning regional issues
Exchange	Exhange of senior/mid-level military officers for joint billets
Educatio	Resident attendance of joint/service/military war/staff colleges
Foreign	Foreign military sales of excess military equipment

Select best theater engagement activity

Node: 10000

Compare the relative PREFERENCE with respect to: GOODWILL < GOAL

	Exercise	Port Vis	Conferen	Exchange	Educatio	Foreign
High Lev	4.0	(4.0)	3.0	4.0	4.0	6.0
Exercise		(2.0)	4.0	4.0	4.0	4.0
Port Vis			4.0	4.0	4.0	6.0
Conferen				3.0	2.0	3.0
Exchange					2.0	3.0
Educatio						3.0

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Select best theater engagement activity
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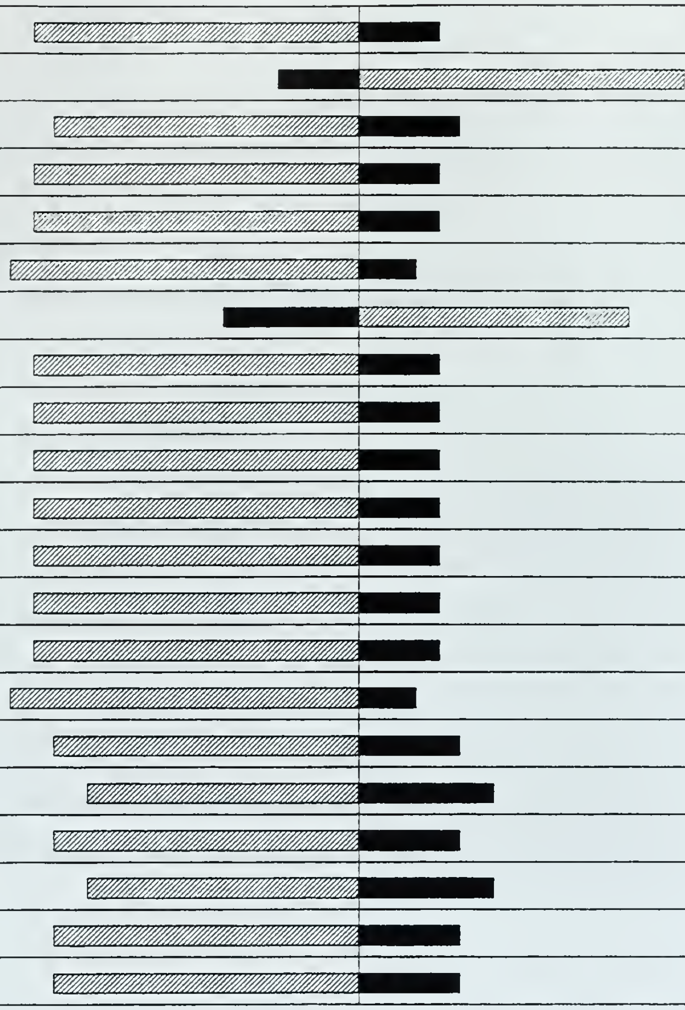
Exchange	Exhange of senior/mid-level military officers for joint billets
Educatio	Resident attendance of joint/service/military war/staff colleges
Foreign	Foreign military sales of excess military equipment

Select best theater engagement activity

Node: 10000

Compare the relative PREFERENCE with respect to: GOODWILL < GOAL

1	High Lev	Exercise
2	High Lev	Port Vis
3	High Lev	Conferen
4	High Lev	Exchange
5	High Lev	Educatio
6	High Lev	Foreign
7	Exercise	Port Vis
8	Exercise	Conferen
9	Exercise	Exchange
10	Exercise	Educatio
11	Exercise	Foreign
12	Port Vis	Conferen
13	Port Vis	Exchange
14	Port Vis	Educatio
15	Port Vis	Foreign
16	Conferen	Exchange
17	Conferen	Educatio
18	Conferen	Foreign
19	Exchange	Educatio
20	Exchange	Foreign
21	Educatio	Foreign



Abbreviation	Definition
Goal	Select best theater engagement activity
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Conferen	Information exchange conferences concerning regional issues
Exchange	Exhange of senior/mid-level military officers for joint billets
Educatio	Resident attendance of joint/service/military war/staff colleges
Foreign	Foreign military sales of excess military equipment

Select best theater engagement activity

Node: 20000

Compare the relative PREFERENCE with respect to: ACCESS < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exercise
2	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Port Vis
3	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
4	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
5	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
6	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
7	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Port Vis
8	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
9	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
10	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
11	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
12	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
13	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
14	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
15	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
16	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
17	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
18	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
19	Exchange	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
20	Exchange	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
21	Educatio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign

Abbreviation	**Definition**
Goal	Select best theater engagement activity
ACCESS	Provide improved access for US
High Lev	Visits/Talks between high level civilians and/or senior military
Exercise	Conduct of joint/combined military training exercises
Port Vis	Port Visit in AOR conducted by ARG, CBG, or single ship
Conferen	Information exchange conferences concerning regional issues
Exchange	Exhange of senior/mid-level military officers for joint billets
Educatio	Resident attendance of joint/service/military war/staff colleges
Foreign	Foreign military sales of excess military equipment

Select best theater engagement activity

Node: 20000

Compare the relative PREFERENCE with respect to: ACCESS < GOAL

	Exercise	Port Vis	Conferen	Exchange	Educatio	Foreign
High Lev	(5.0)	(5.0)	4.0	4.0	4.0	5.0
Exercise		(3.0)	6.0	6.0	6.0	6.0
Port Vis			6.0	6.0	6.0	7.0
Conferen				3.0	3.0	4.0
Exchange					1.0	3.0
Educatio						3.0

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Select best theater engagement activity
ACCESS	Provide improved access for US
High Lev	Visits/Talks between high level civilians and/or senior military
Exercise	Conduct of joint/combined military training exercises
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Select best theater engagement activity

Node: 20000

Compare the relative PREFERENCE with respect to: ACCESS < GOAL

1	High Lev	Exercise
2	High Lev	Port Vis
3	High Lev	Conferen
4	High Lev	Exchange
5	High Lev	Educatio
6	High Lev	Foreign
7	Exercise	Port Vis
8	Exercise	Conferen
9	Exercise	Exchange
10	Exercise	Educatio
11	Exercise	Foreign
12	Port Vis	Conferen
13	Port Vis	Exchange
14	Port Vis	Educatio
15	Port Vis	Foreign
16	Conferen	Exchange
17	Conferen	Educatio
18	Conferen	Foreign
19	Exchange	Educatio
20	Exchange	Foreign
21	Educatio	Foreign

Abbreviation	Definition
Goal	Select best theater engagement activity
ACCESS	Provide improved access for US
High Lev	Visits/Talks between high level civilians and/or senior military
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Exchange	Exhange of senior/mid-level military officers for joint billets
Educatio	Resident attendance of joint/service/military war/staff colleges
Foreign	Foreign military sales of excess military equipment

Select best theater engagement activity

Node: 30000

Compare the relative PREFERENCE with respect to: PARTNER < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exercise
2	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Port Vis
3	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
4	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
5	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
6	High Lev	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
7	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Port Vis
8	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
9	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
10	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
11	Exercise	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
12	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Conferen
13	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
14	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
15	Port Vis	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
16	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Exchange
17	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
18	Conferen	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
19	Exchange	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educatio
20	Exchange	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign
21	Educatio	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Foreign

Abbreviation	Definition
Goal	Select best theater engagement activity
PARTNER	Develop coalition partner in a particular AOR
High Lev	Visits/Talks between high level civilians and/or senior military
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Foreign	Foreign military sales of excess military equipment

Select best theater engagement activity

Node: 30000

Compare the relative PREFERENCE with respect to: PARTNER < GOAL

	Exercise	Port Vis	Conferen	Exchange	Educatio	Foreign
High Lev	2.0	3.0	2.0	4.0	4.0	2.0
Exercise		2.0	3.0	4.0	4.0	2.0
Port Vis			(2.0)	2.0	2.0	2.0
Conferen				3.0	2.0	2.0
Exchange					2.0	(2.0)
Educatio						(2.0)

Row element is __ times more than column element unless enclosed in ()

Abbreviation	**Definition**
Goal	Select best theater engagement activity
PARTNER	Develop coalition partner in a particular AOR
High Lev	Visits/Talks between high level civilians and/or senior military
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Select best theater engagement activity

Node: 30000

Compare the relative PREFERENCE with respect to: PARTNER < GOAL

1	High Lev	Exercise
2	High Lev	Port Vis
3	High Lev	Conferen
4	High Lev	Exchange
5	High Lev	Educatio
6	High Lev	Foreign
7	Exercise	Port Vis
8	Exercise	Conferen
9	Exercise	Exchange
10	Exercise	Educatio
11	Exercise	Foreign
12	Port Vis	Conferen
13	Port Vis	Exchange
14	Port Vis	Educatio
15	Port Vis	Foreign
16	Conferen	Exchange
17	Conferen	Educatio
18	Conferen	Foreign
19	Exchange	Educatio
20	Exchange	Foreign
21	Educatio	Foreign

Abbreviation	Definition
Goal	Select best theater engagement activity
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Educatio	Resident attendance of joint/service/military war/staff colleges
Foreign	Foreign military sales of excess military equipment

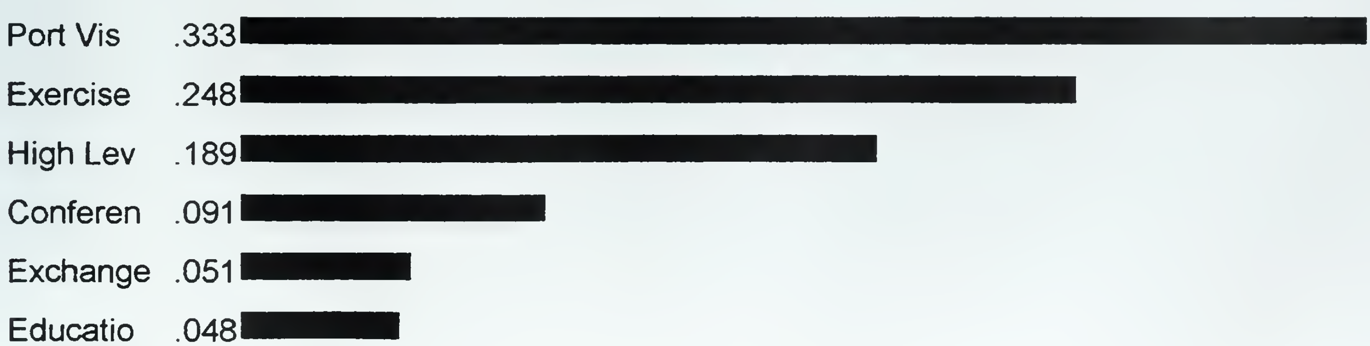
Select best theater engagement activity

Synthesis of Leaf Nodes with respect to GOAL

Ideal Mode

OVERALL INCONSISTENCY INDEX = 0.07

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
ACCESS =.625				
	Port Vis=.625			
	Exercise=.451			
	High Lev=.213			
	Conferen=.119			
	Exchange=.069			
	Educatio=.069			
	Foreign =.042			
GOODWILL=.238				
	Port Vis=.238			
	High Lev=.172			
	Exercise=.119			
	Conferen=.061			
	Exchange=.043			
	Educatio=.037			
	Foreign =.021			
PARTNER =.136				
	High Lev=.136			
	Exercise=.114			
	Conferen=.072			
	Port Vis=.055			
	Foreign =.048			
	Exchange=.030			
	Educatio=.026			



Select best theater engagement activity

Foreign .040[redacted]

Abbreviation	Definition
GOAL	
ACCESS	Provide improved access for US
Conferen	Information exchange conferences concerning regional issues
Educatio	Resident attendance of joint/service/military war/staff colleges
Exchange	Exhange of senior/mid-level military officers for joint billets
Exercise	Conduct of joint/combined military training exercises
Foreign	Foreign military sales of excess military equipment
GOODWILL	Foster goodwill relations among US/countries in a particular AOR
High Lev	Visits/Talks between high level civilians and/or senior military
PARTNER	Develop coalition partner in a particular AOR
Port Vis	Port Visit in AOR conducted by ARG, CBG, or single ship

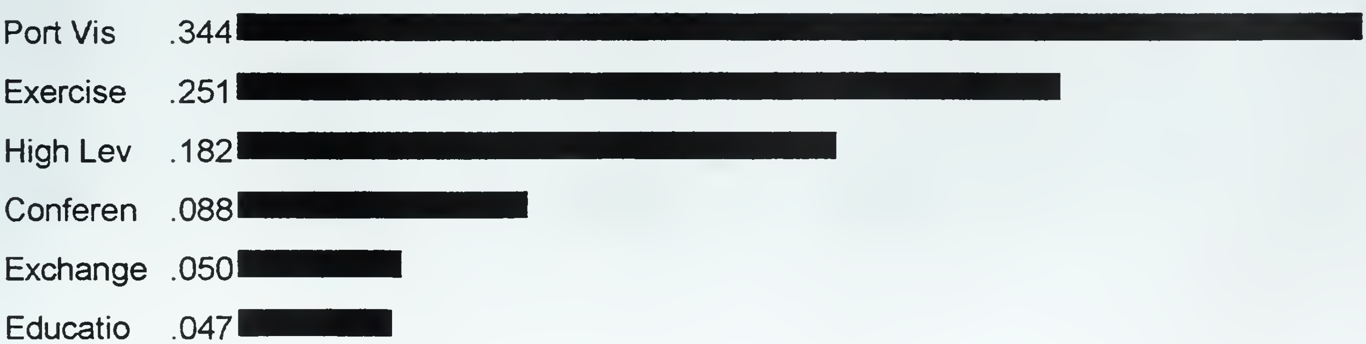
Select best theater engagement activity

Synthesis of Leaf Nodes with respect to GOAL

Distributive Mode

OVERALL INCONSISTENCY INDEX = 0.07

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
ACCESS =.625				
	Port Vis=.246			
	Exercise=.177			
	High Lev=.084			
	Conferen=.047			
	Exchange=.027			
	Educatio=.027			
	Foreign =.016			
GOODWILL=.238				
	Port Vis=.082			
	High Lev=.059			
	Exercise=.041			
	Conferen=.021			
	Exchange=.015			
	Educatio=.013			
	Foreign =.007			
PARTNER =.136				
	High Lev=.039			
	Exercise=.032			
	Conferen=.020			
	Port Vis=.016			
	Foreign =.014			
	Exchange=.009			
	Educatio=.007			

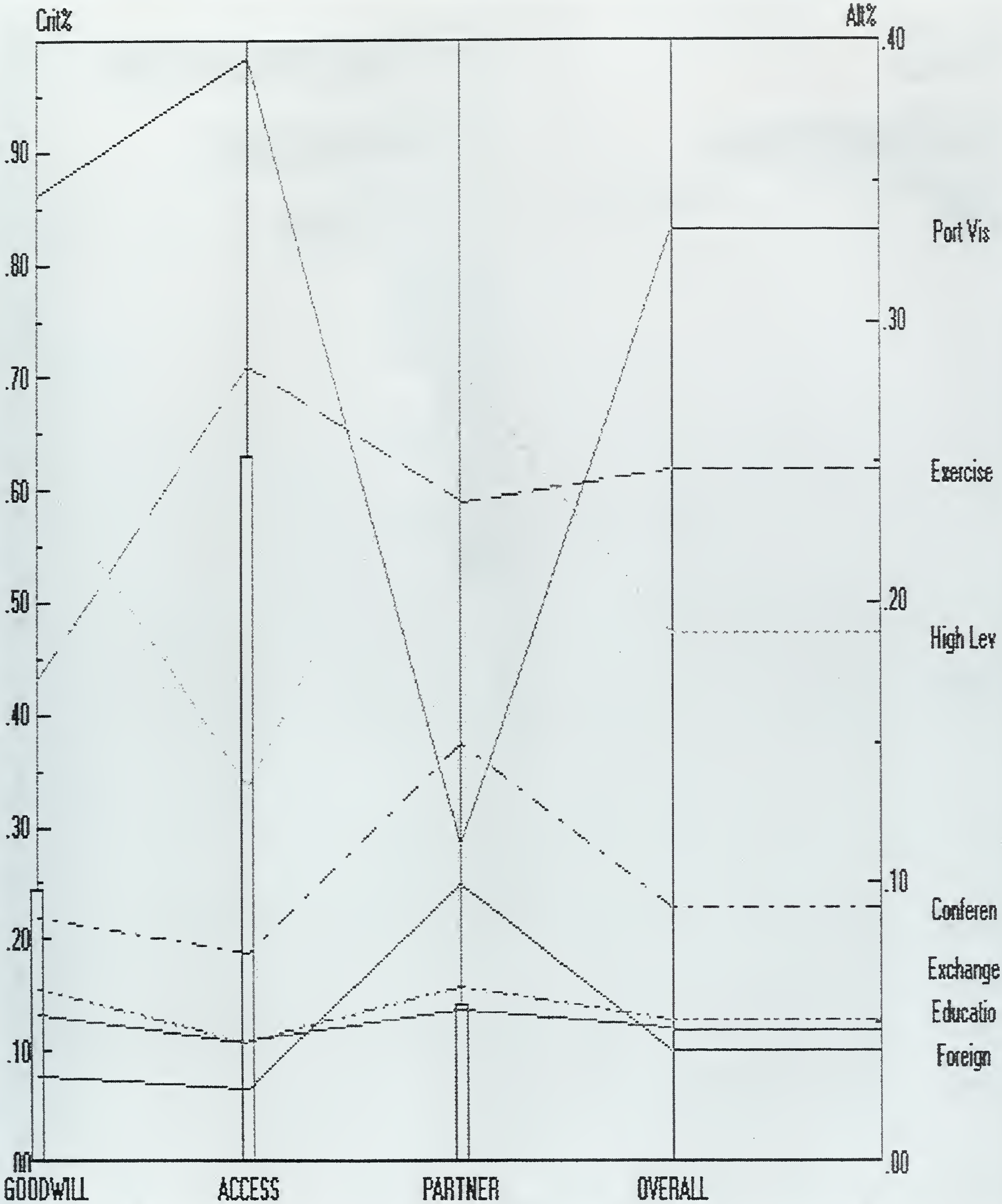


Select best theater engagement activity

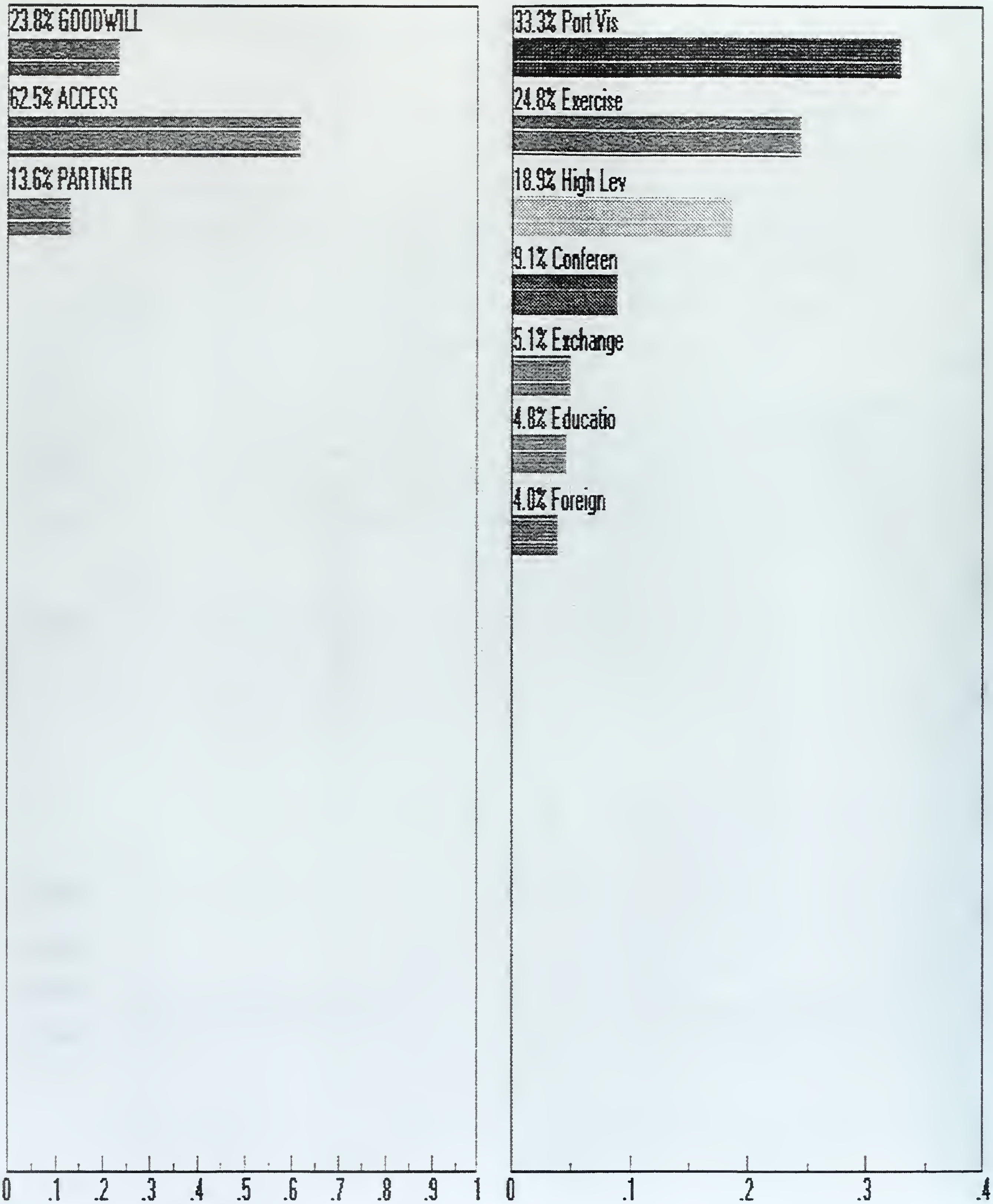
Foreign .037 [redacted]

Abbreviation	Definition
GOAL	
ACCESS	Provide improved access for US
Conferen	Information exchange conferences concerning regional issues
Educatio	Resident attendance of joint/service/military war/staff colleges
Exchange	Exhange of senior/mid-level military officers for joint billets
Exercise	Conduct of joint/combined military training exercises
Foreign	Foreign military sales of excess military equipment
GOODWILL	Foster goodwill relations among US/countries in a particular AOR
High Lev	Visits/Talks between high level civilians and/or senior military
PARTNER	Develop coalition partner in a particular AOR
Port Vis	Port Visit in AOR conducted by ARG, CBG, or single ship

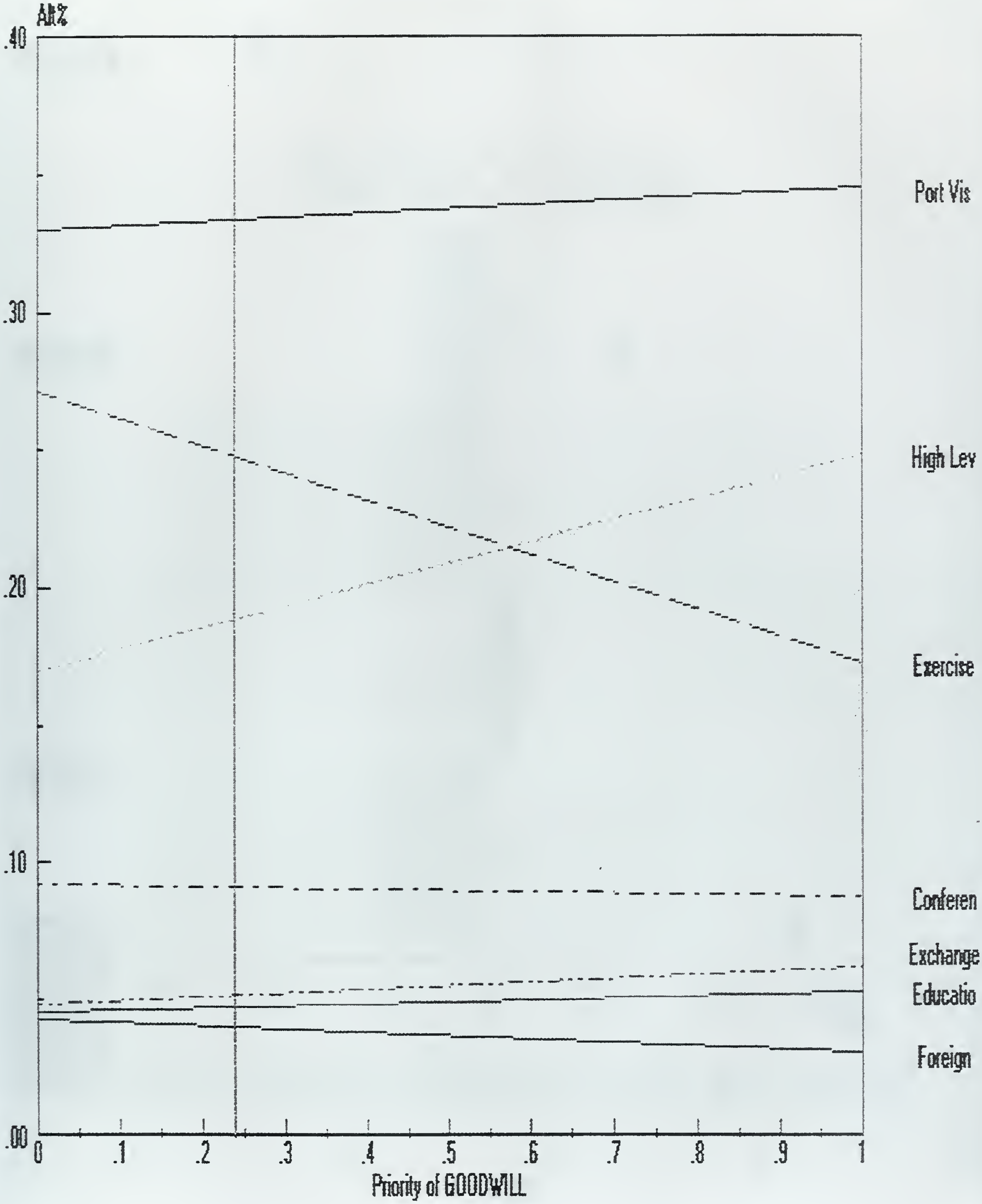
Performance Sensitivity w.r.t. GOAL for nodes below GOAL



Dynamic Sensitivity w.r.t. GOAL for nodes below GOAL

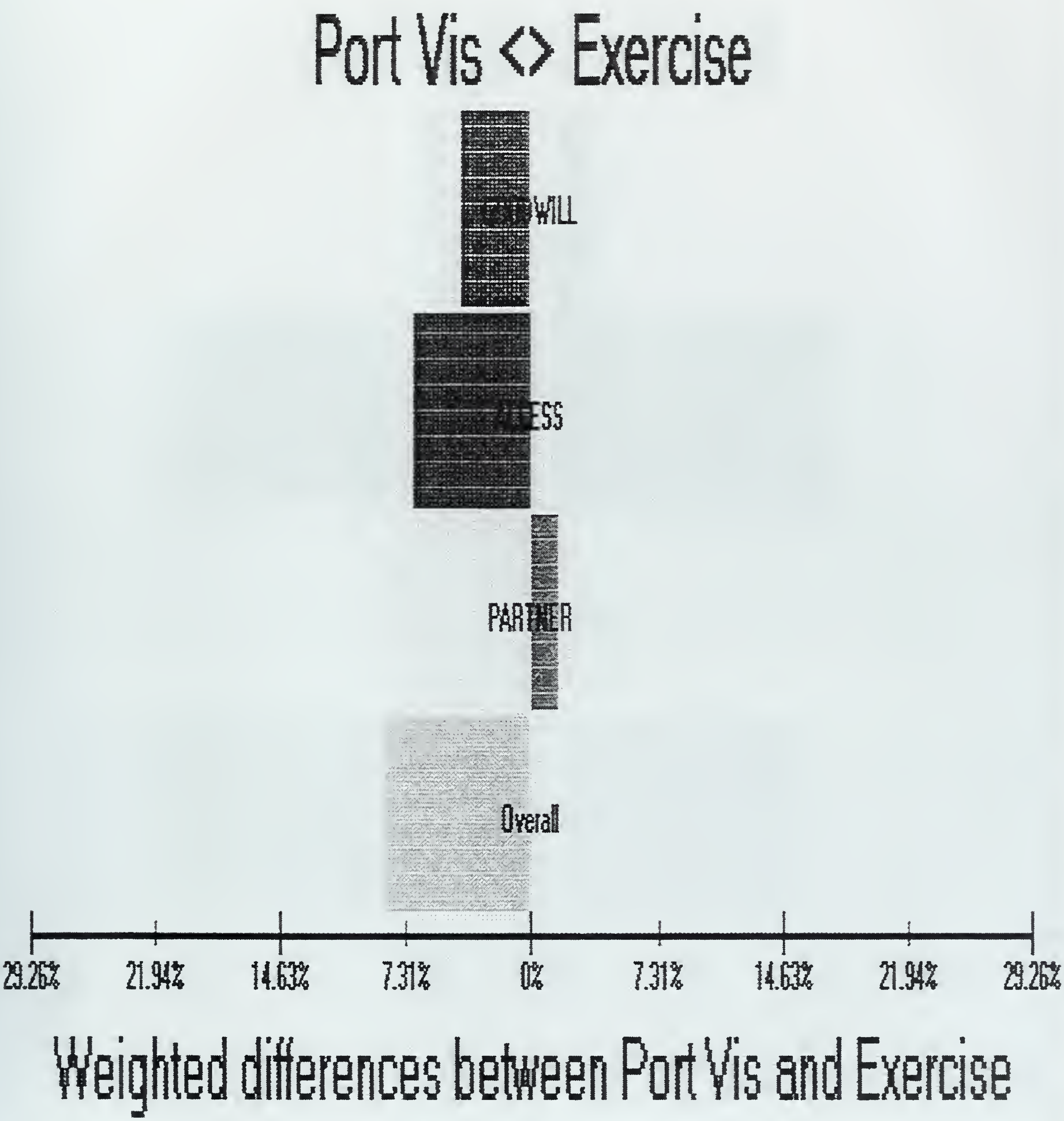


Gradient Sensitivity w.r.t. GOAL for nodes below GOAL

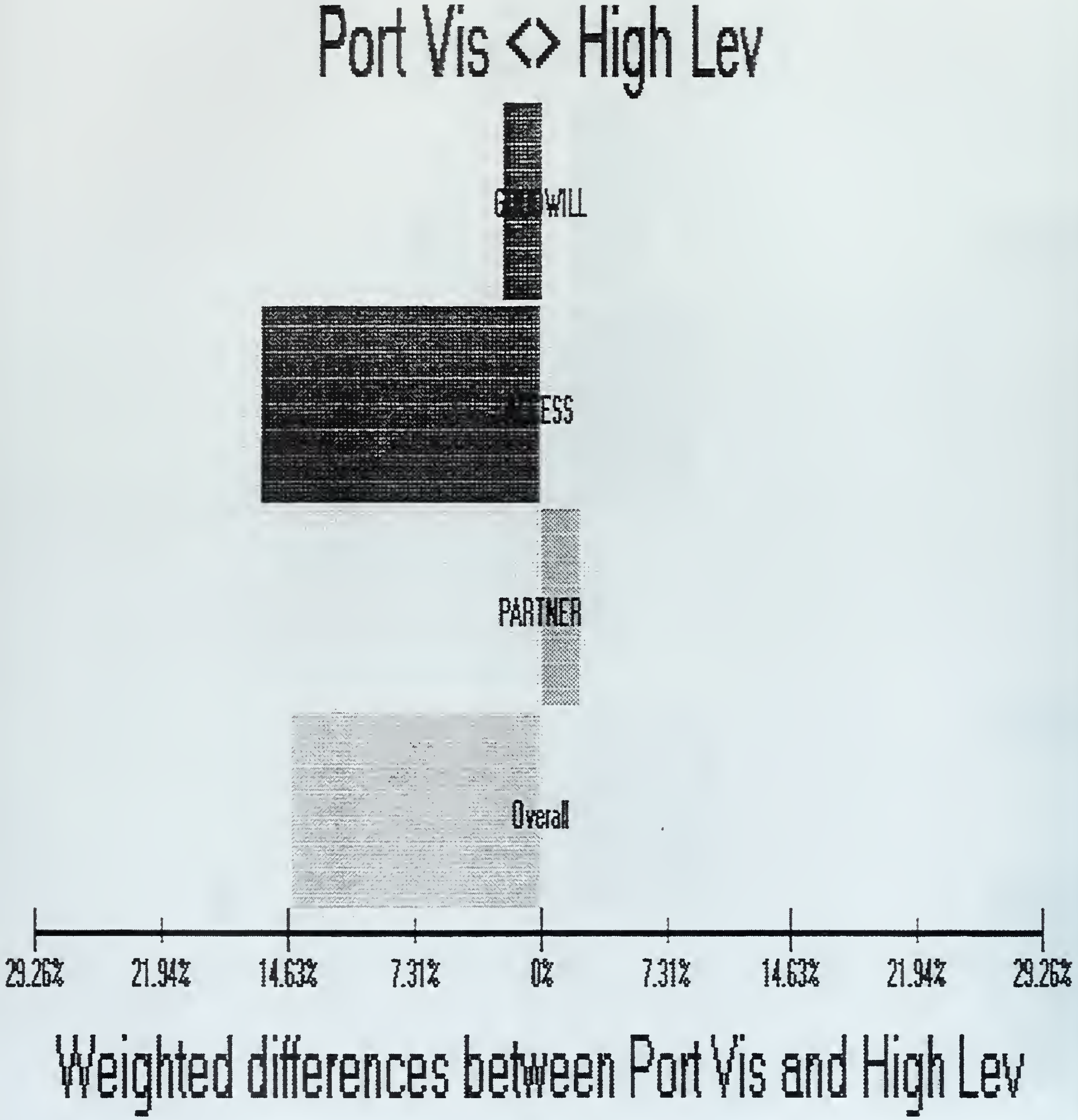


Two-D Sensitivity w.r.t. GOAL for nodes below GOAL

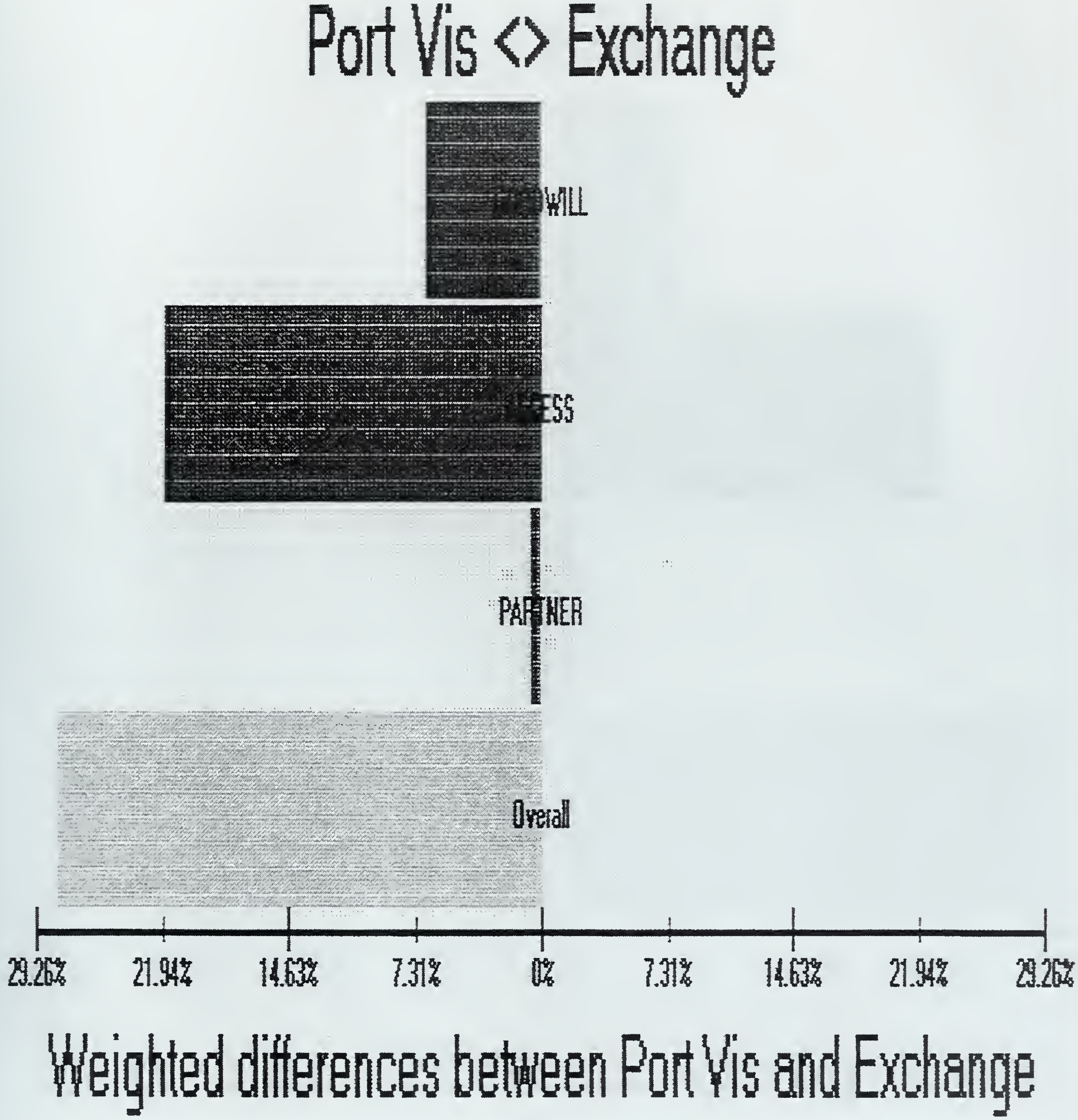
Differences Sensitivity w.r.t. GOAL for nodes below GOAL



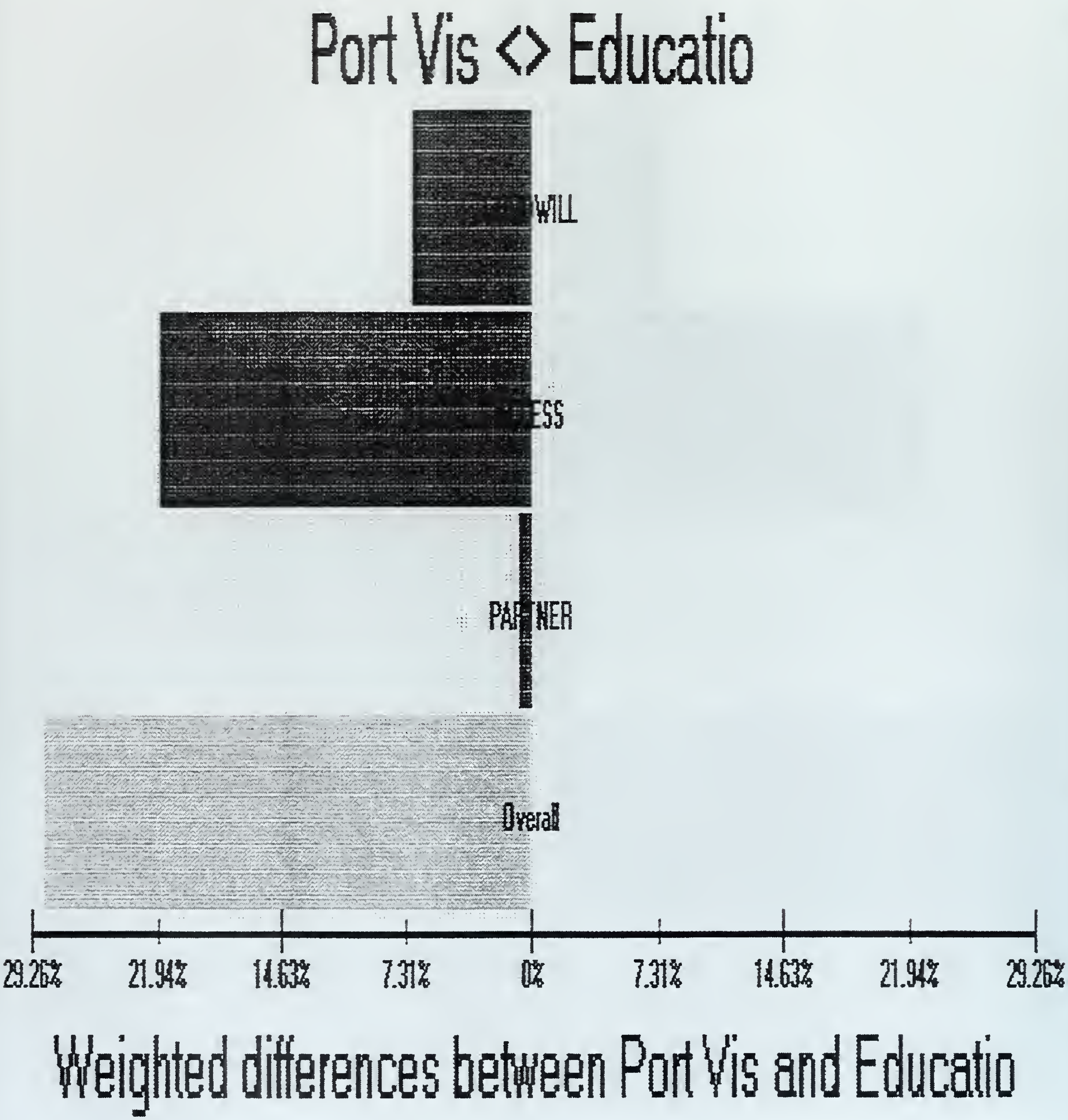
Differences Sensitivity w.r.t. GOAL for nodes below GOAL

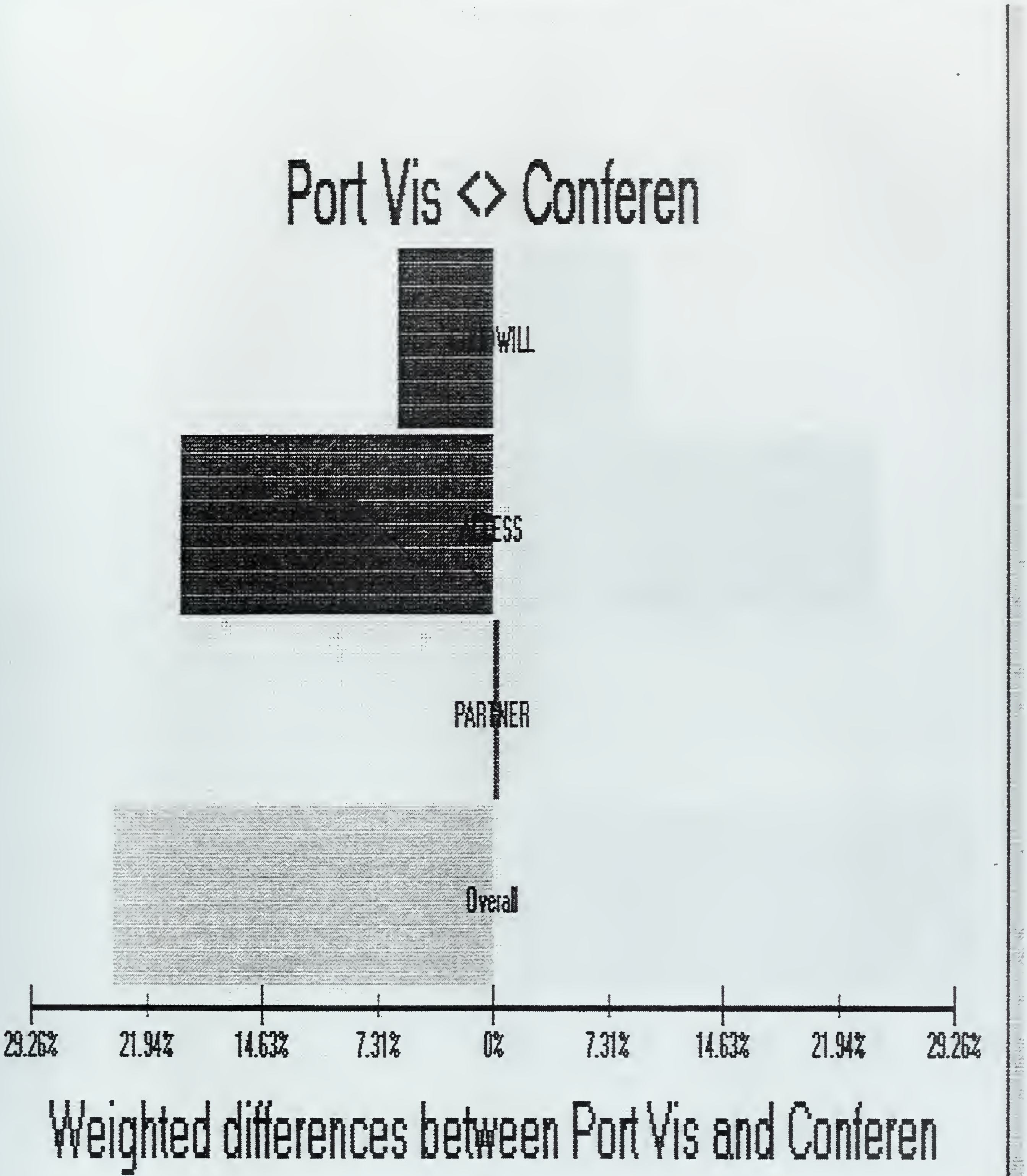


Differences Sensitivity w.r.t. GOAL for nodes below GOAL



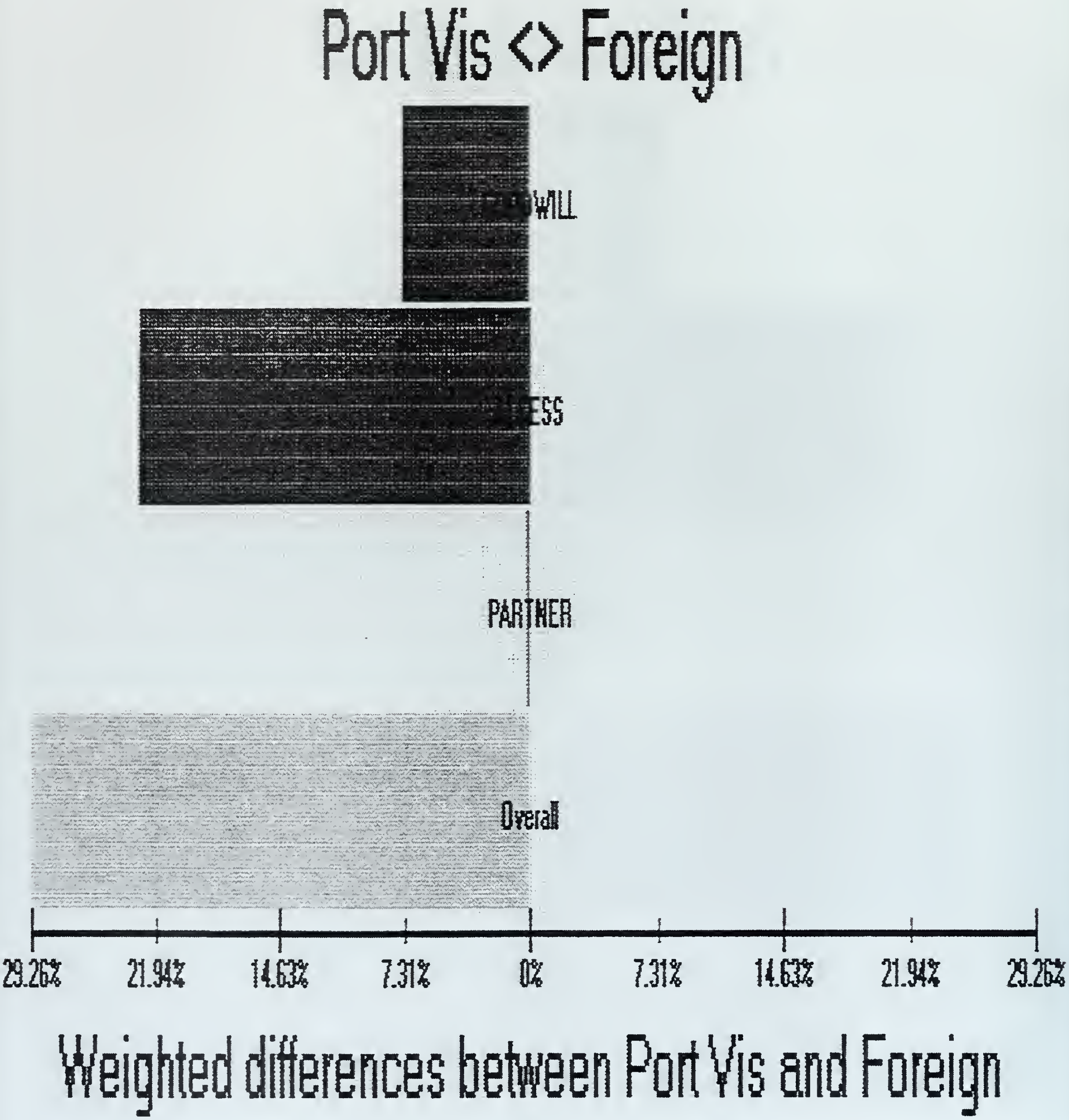
Differences Sensitivity w.r.t. GOAL for nodes below GOAL



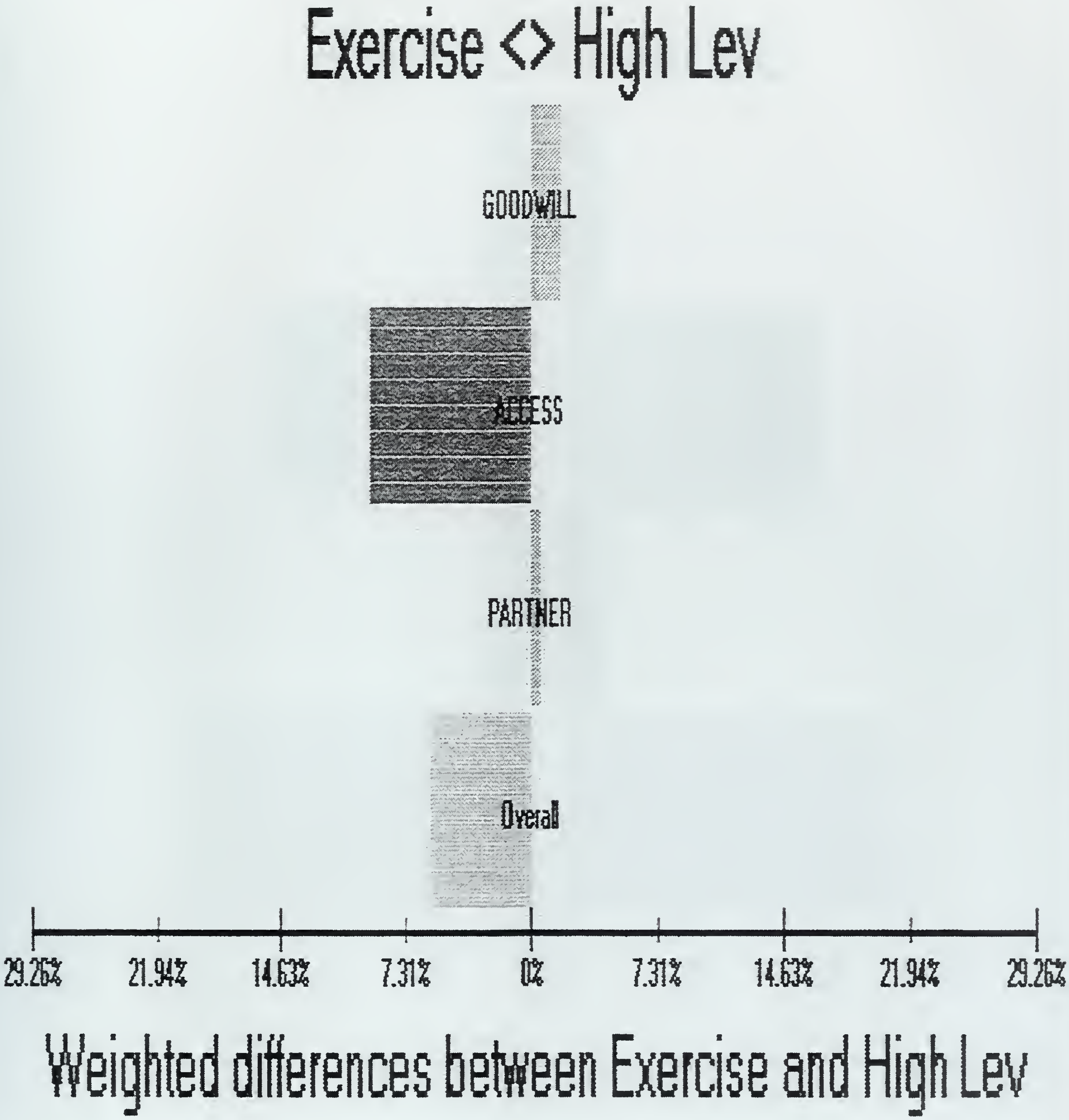


Port Vis <> Conferen
WILL
ESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between Port Vis and Conferen

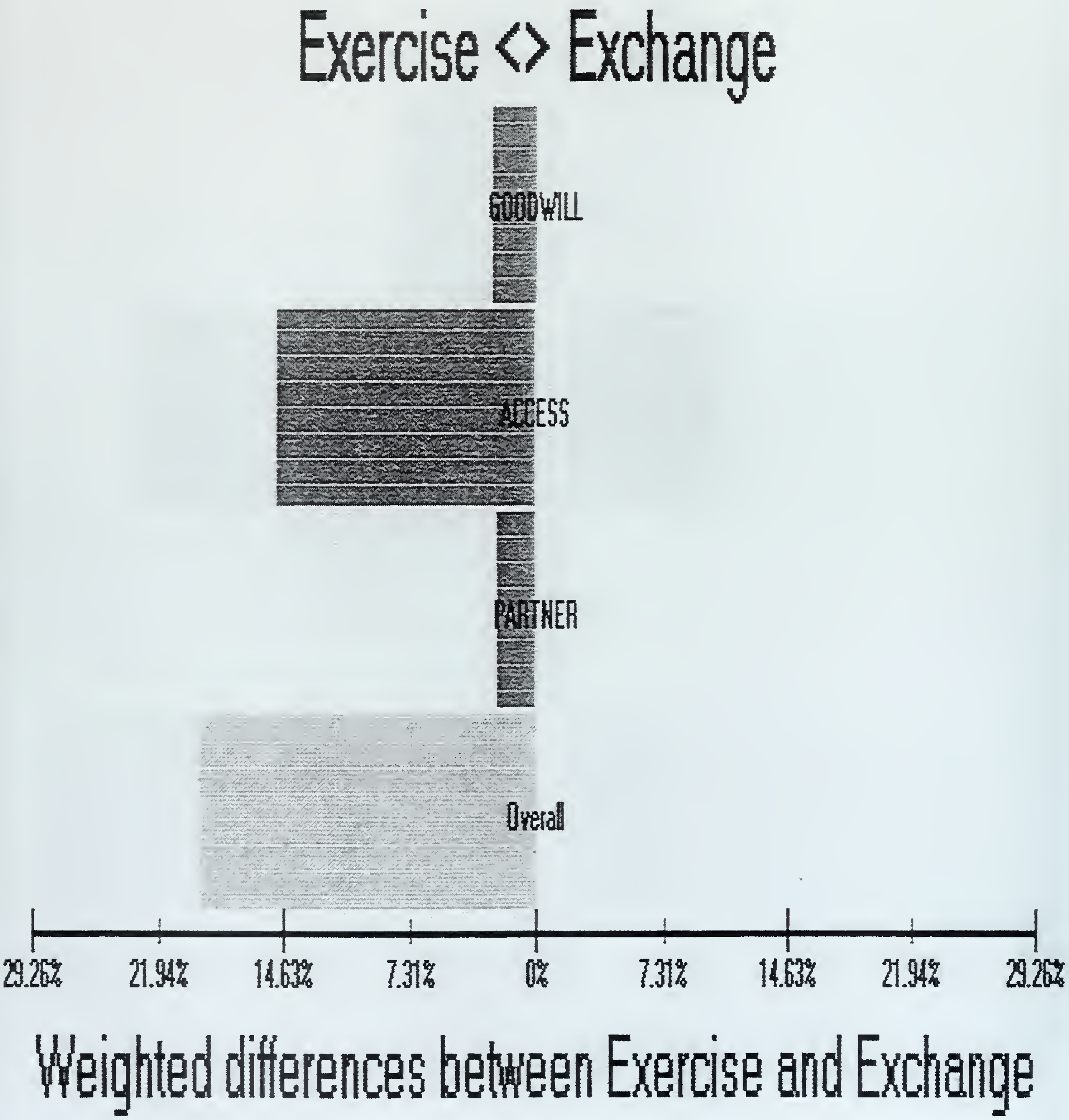
Differences Sensitivity w.r.t. GOAL for nodes below GOAL

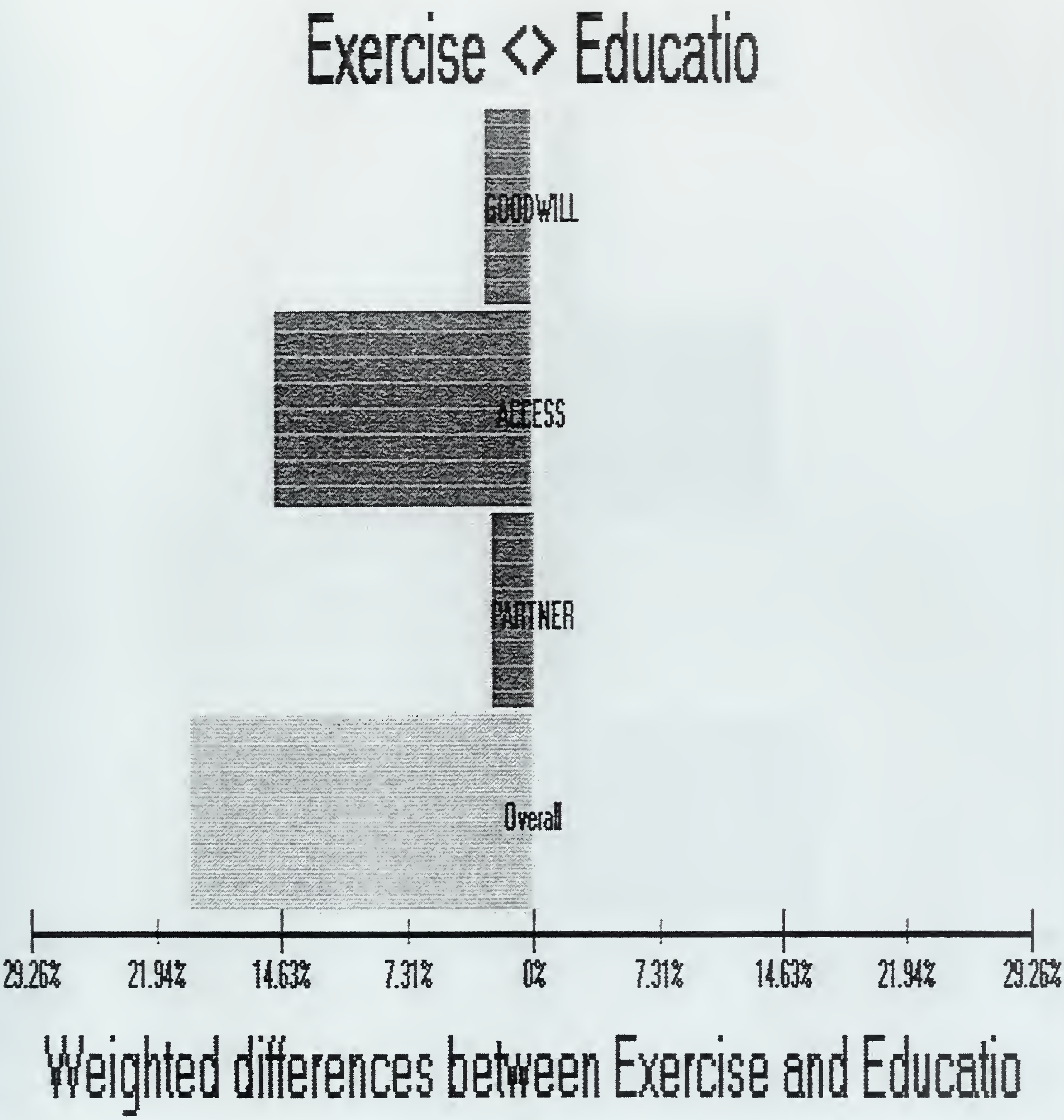


Differences Sensitivity w.r.t. GOAL for nodes below GOAL

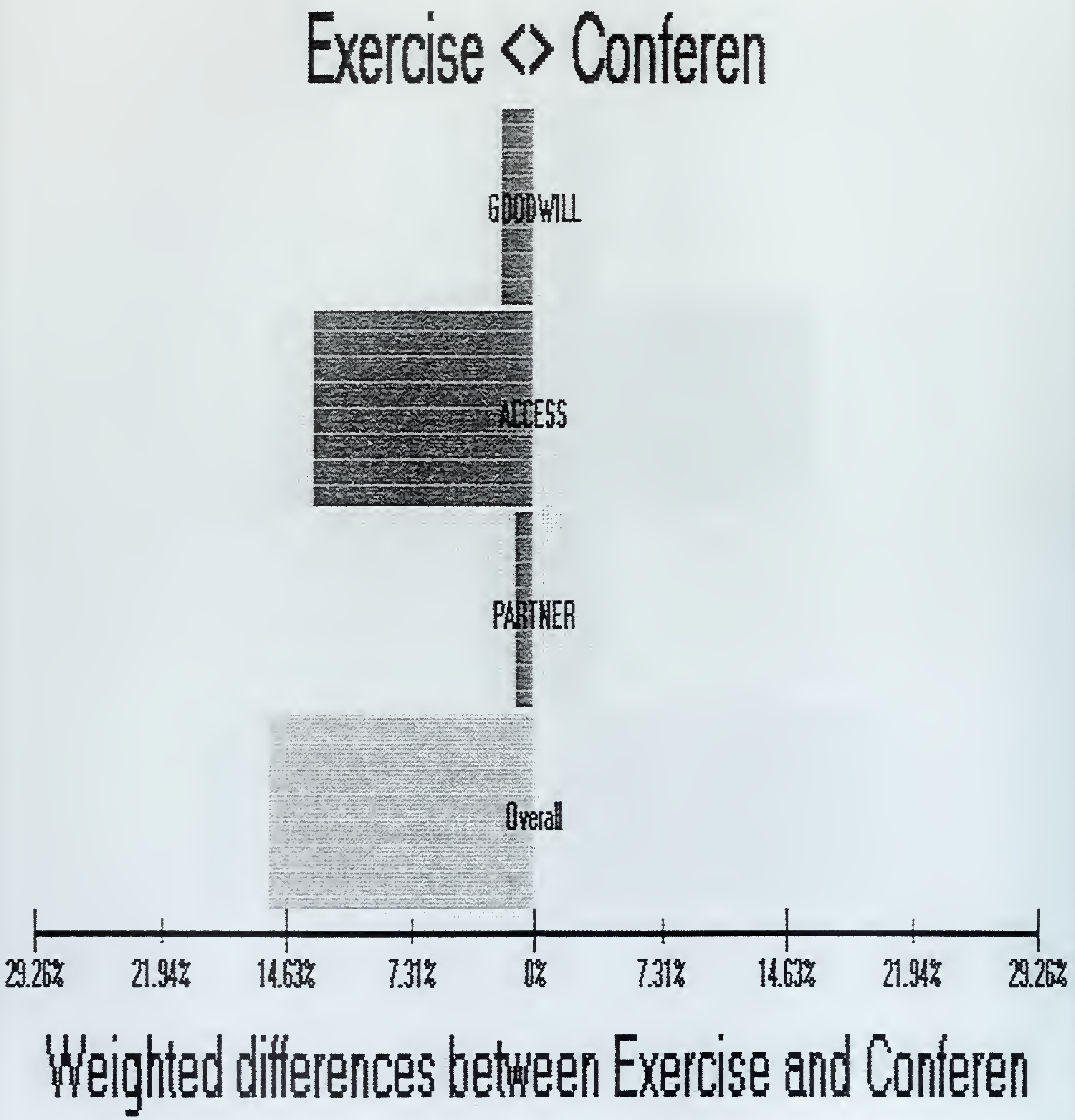


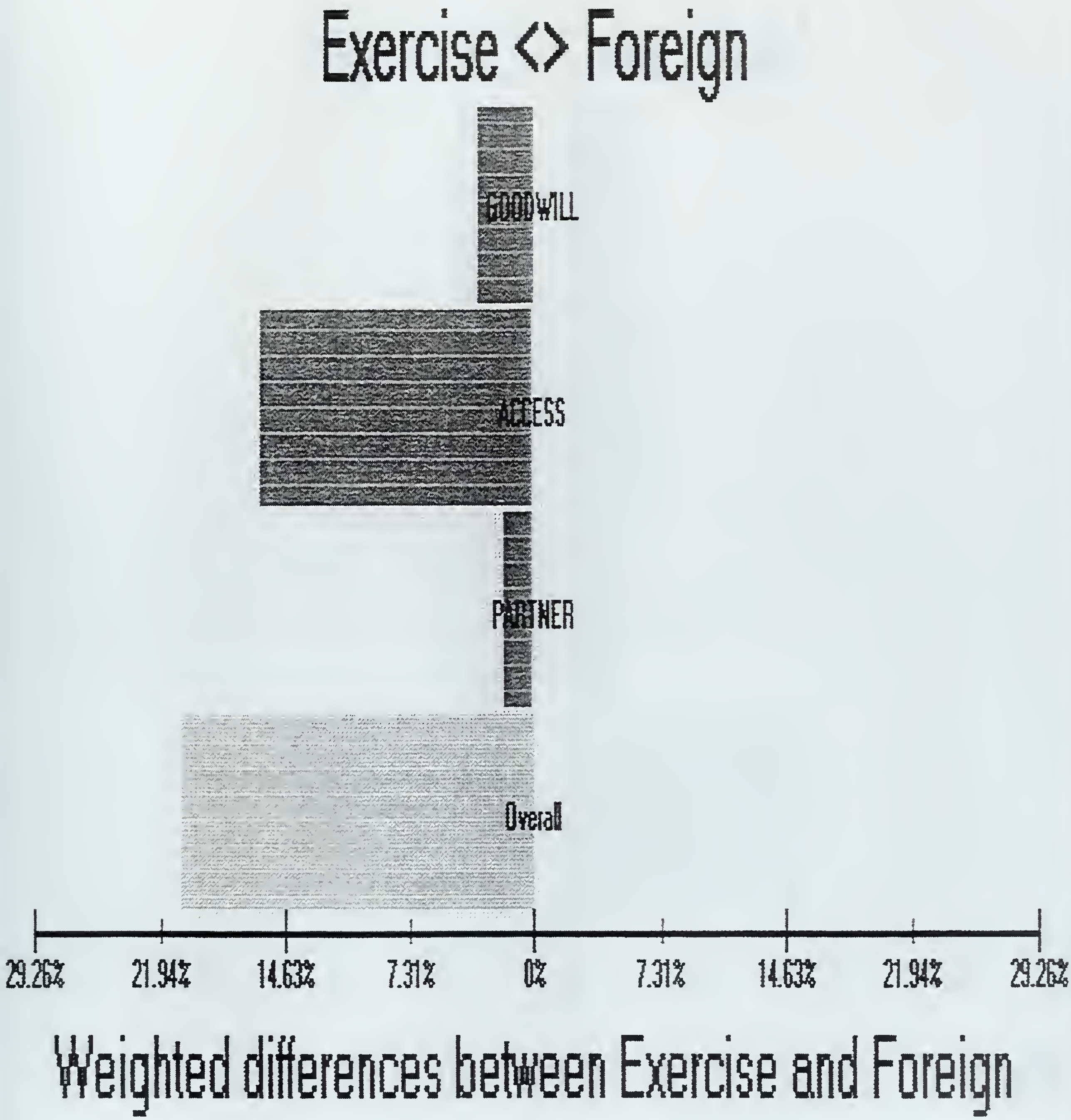
Differences Sensitivity w.r.t. GOAL for nodes below GOAL

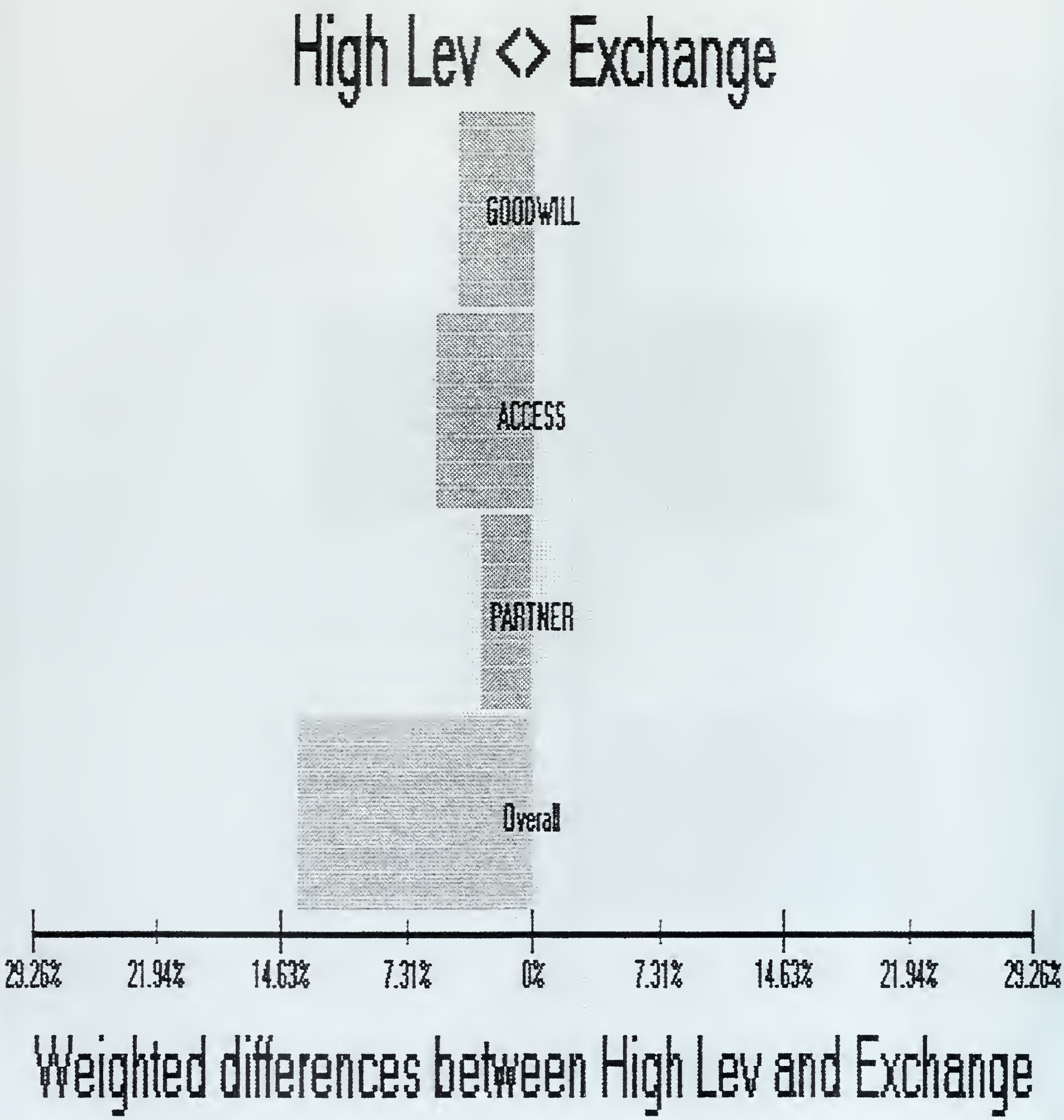



Exercise <> Educatio
GOODWILL
ACCESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between Exercise and Educatio

Differences Sensitivity w.r.t. GOAL for nodes below GOAL

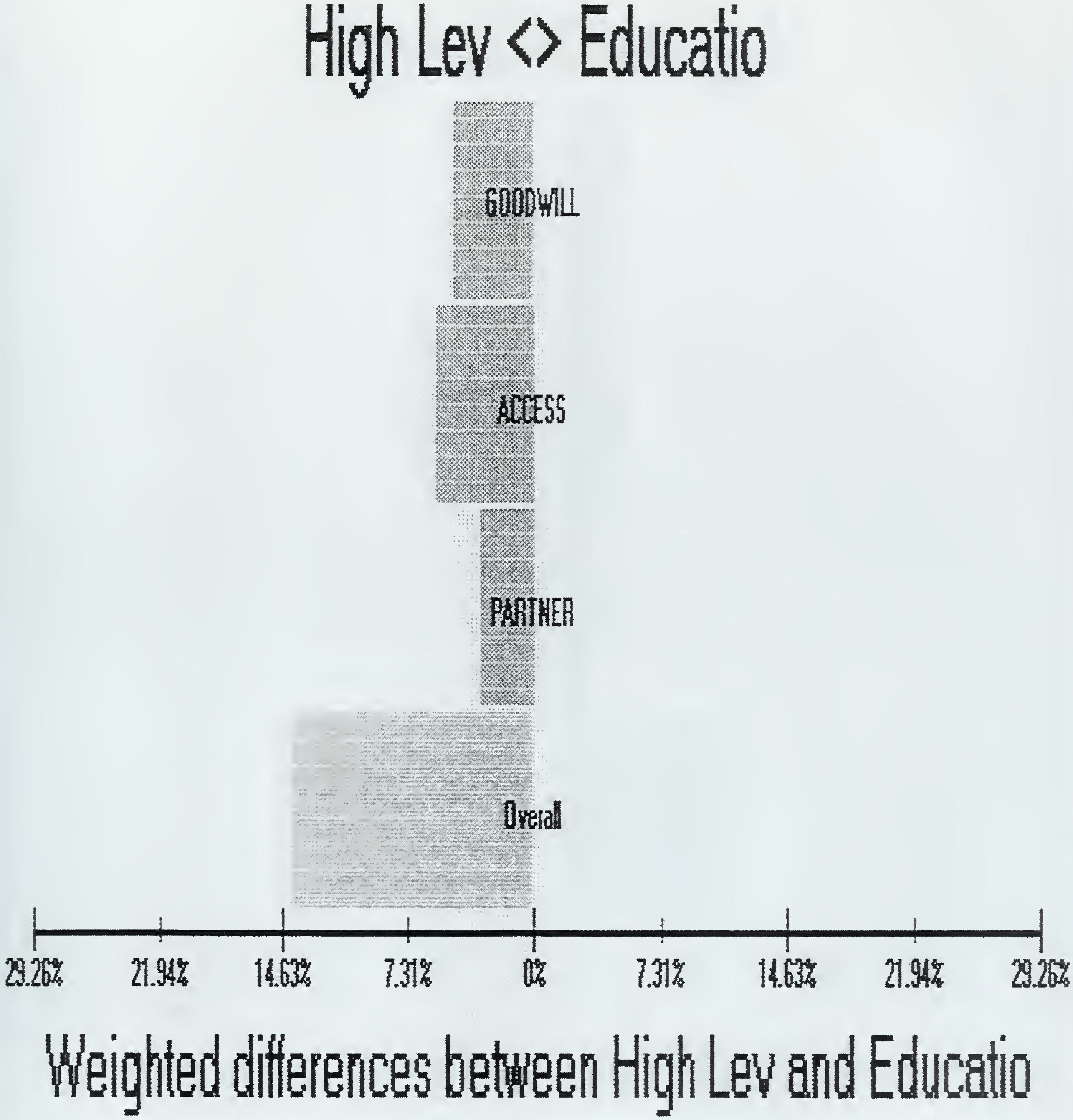


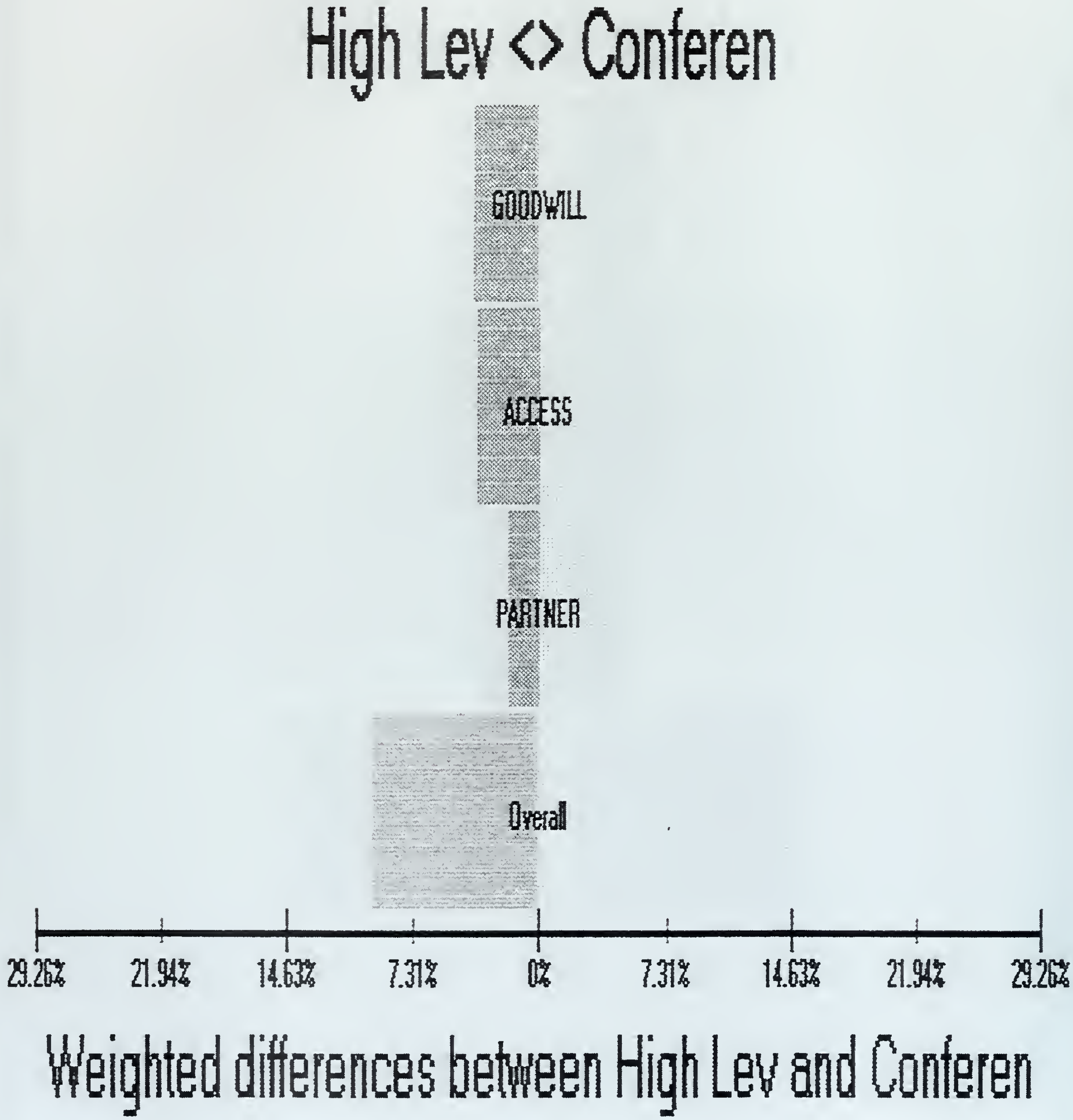

Exercise <> Foreign
GOODWILL
ACCESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between Exercise and Foreign

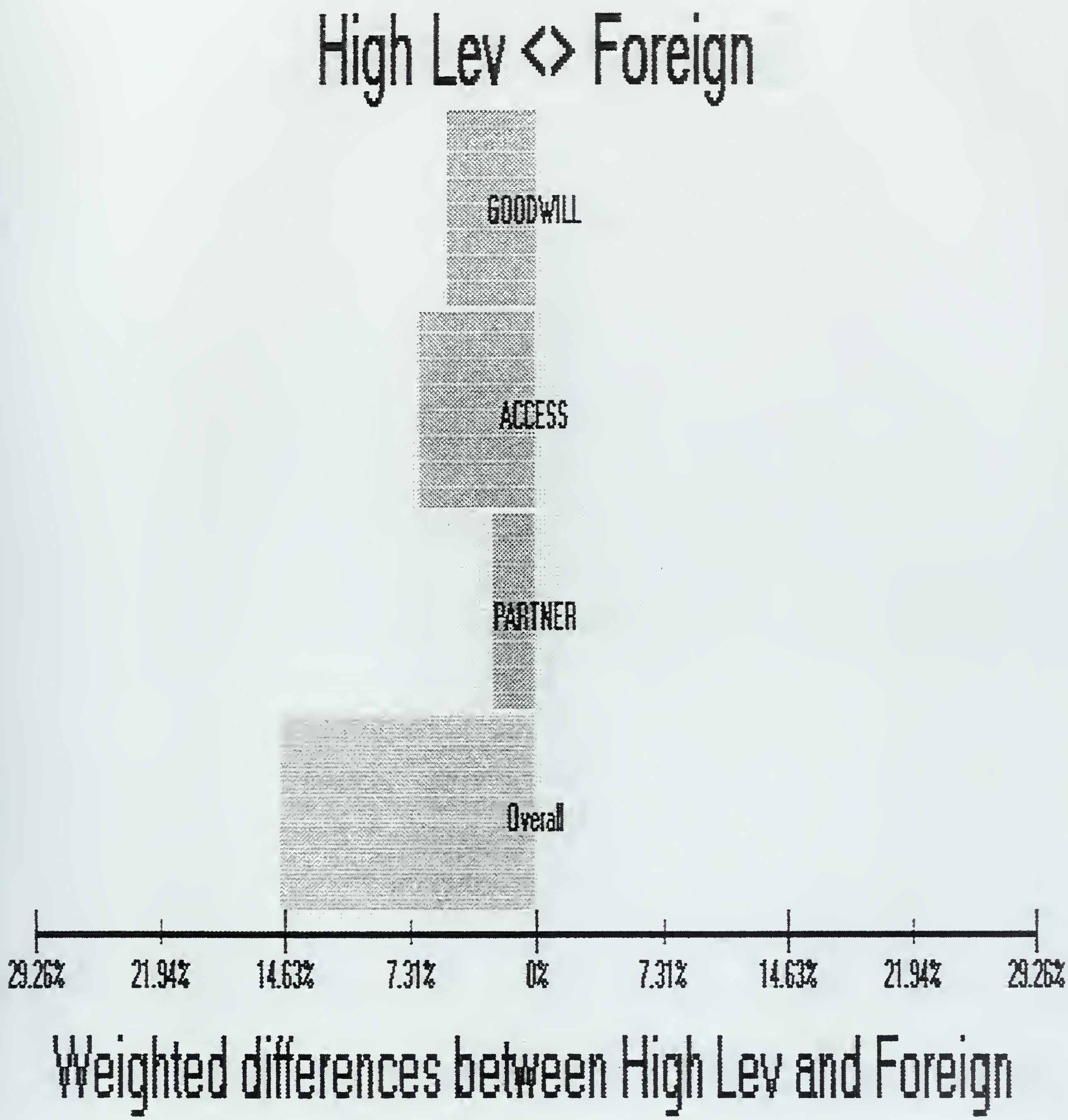


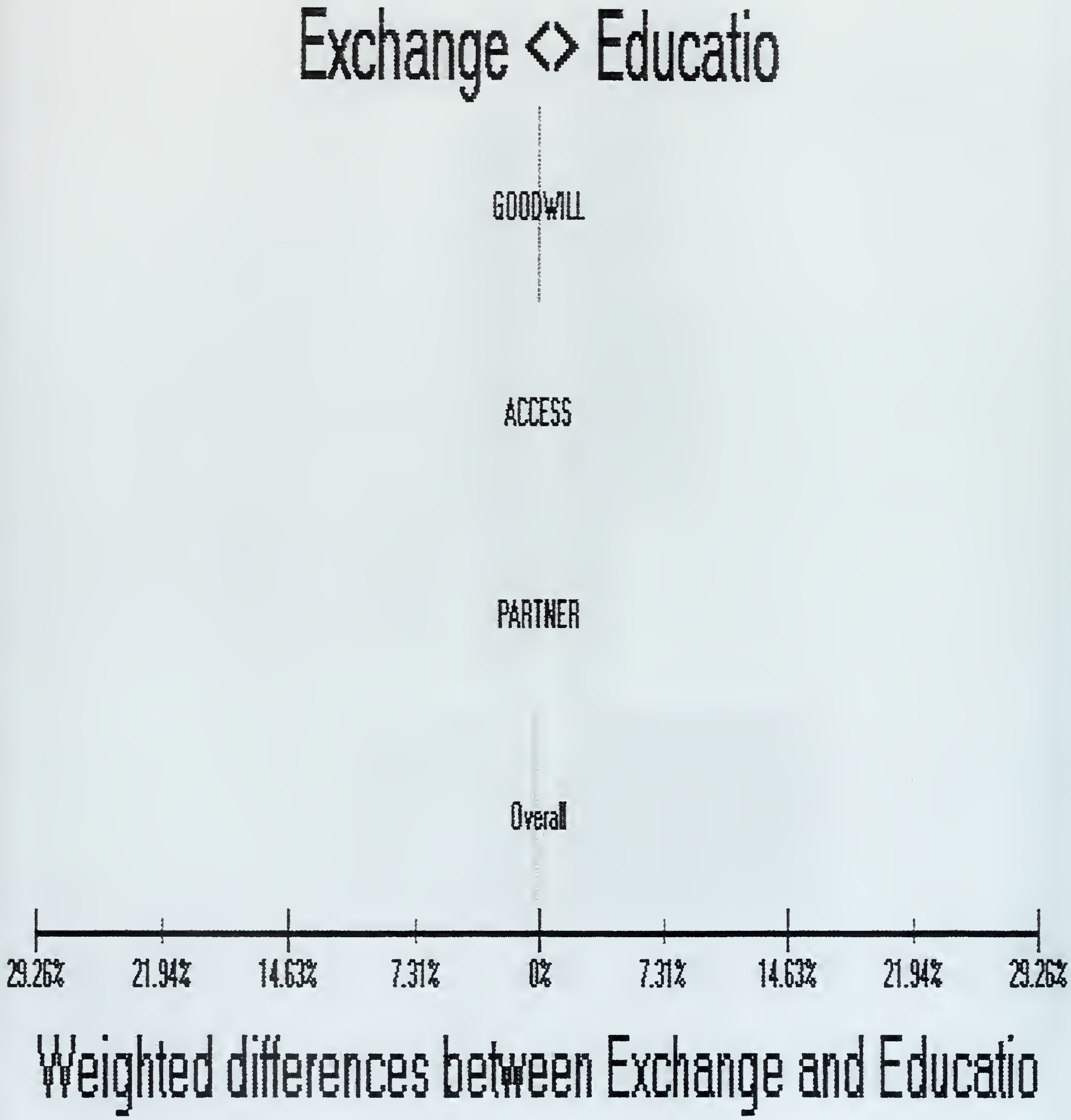
High Lev <> Exchange
GOODWILL
ACCESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between High Lev and Exchange

Differences Sensitivity w.r.t. GOAL for nodes below GOAL

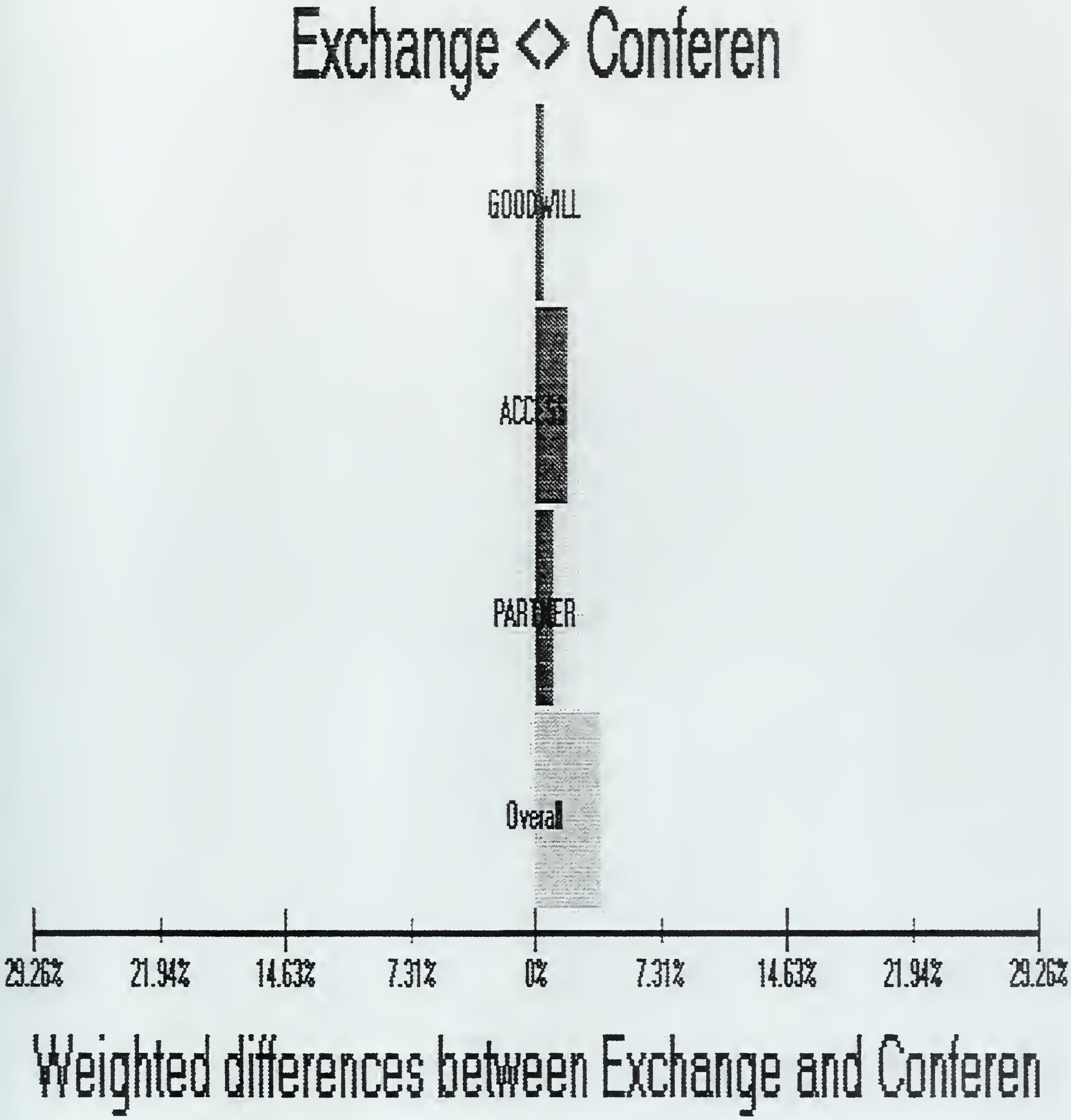



High Lev <> Conferen
GOODWILL
ACCESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between High Lev and Conferen

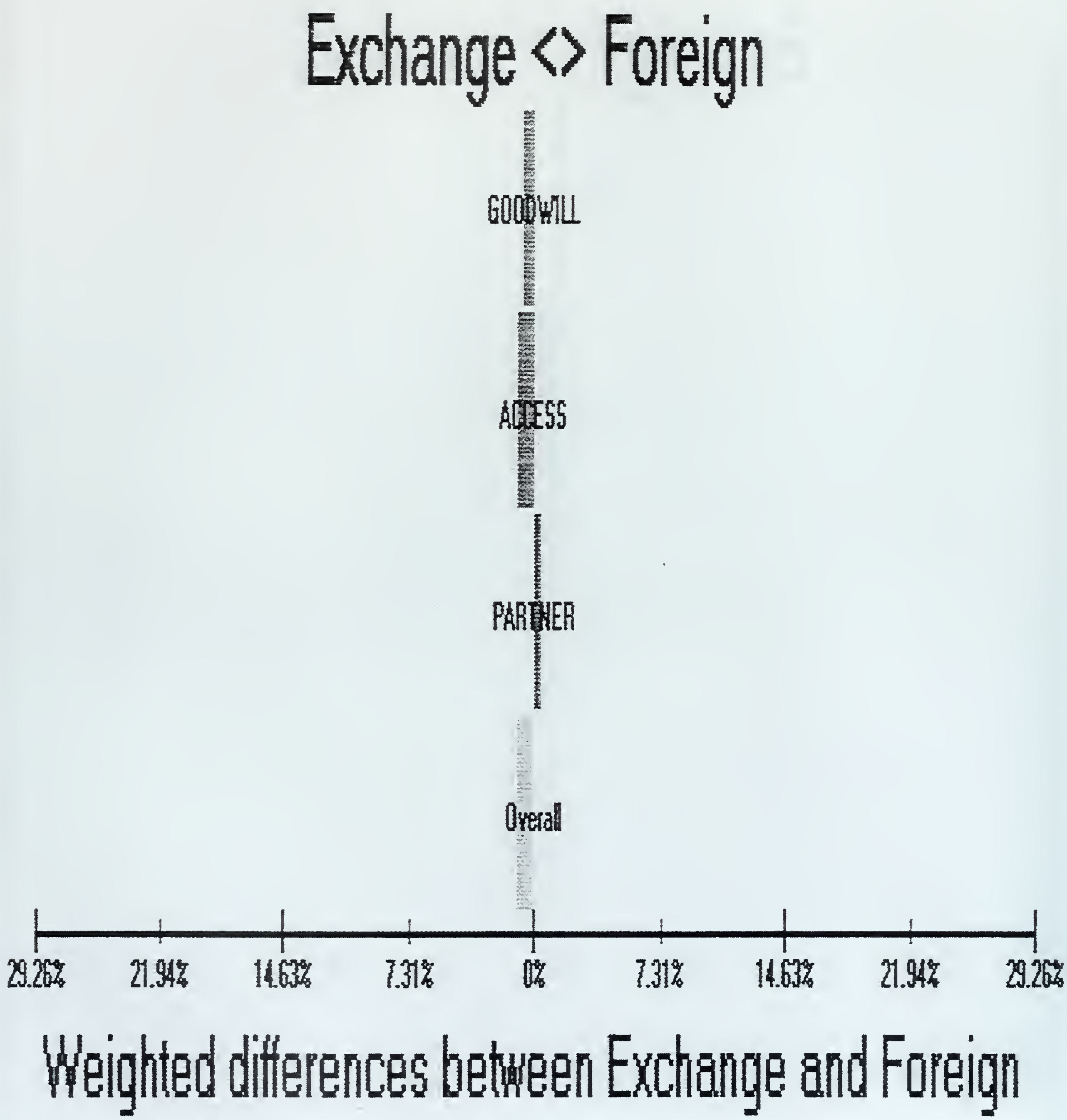

High Lev <> Foreign
GOODWILL
ACCESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between High Lev and Foreign


Exchange <> Educatio
GOODWILL
ACCESS
PARTNER
Overall
29.26%
21.94%
14.63%
7.31%
0%
7.31%
14.63%
21.94%
29.26%
Weighted differences between Exchange and Educatio

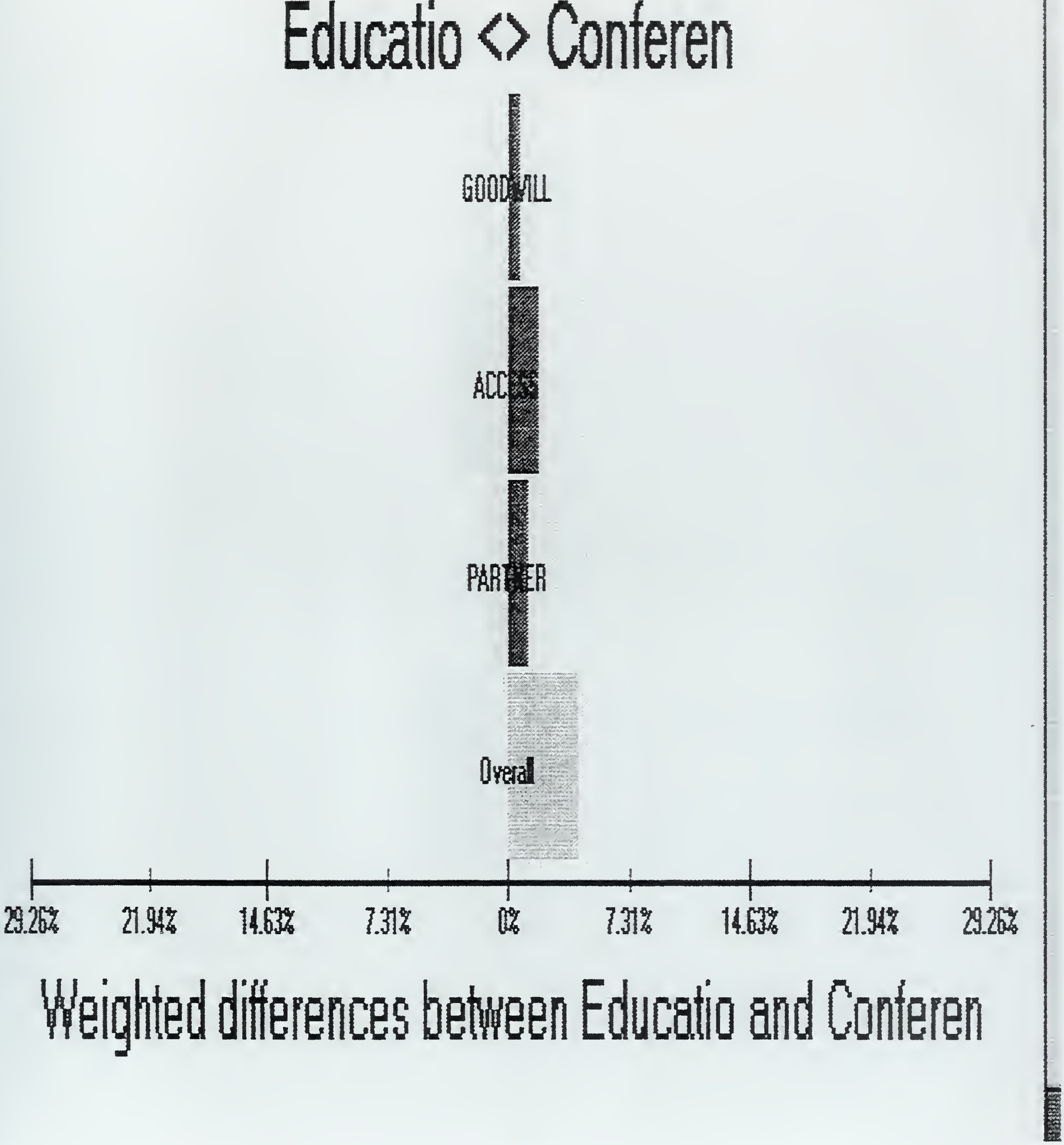
Differences Sensitivity w.r.t. GOAL for nodes below GOAL



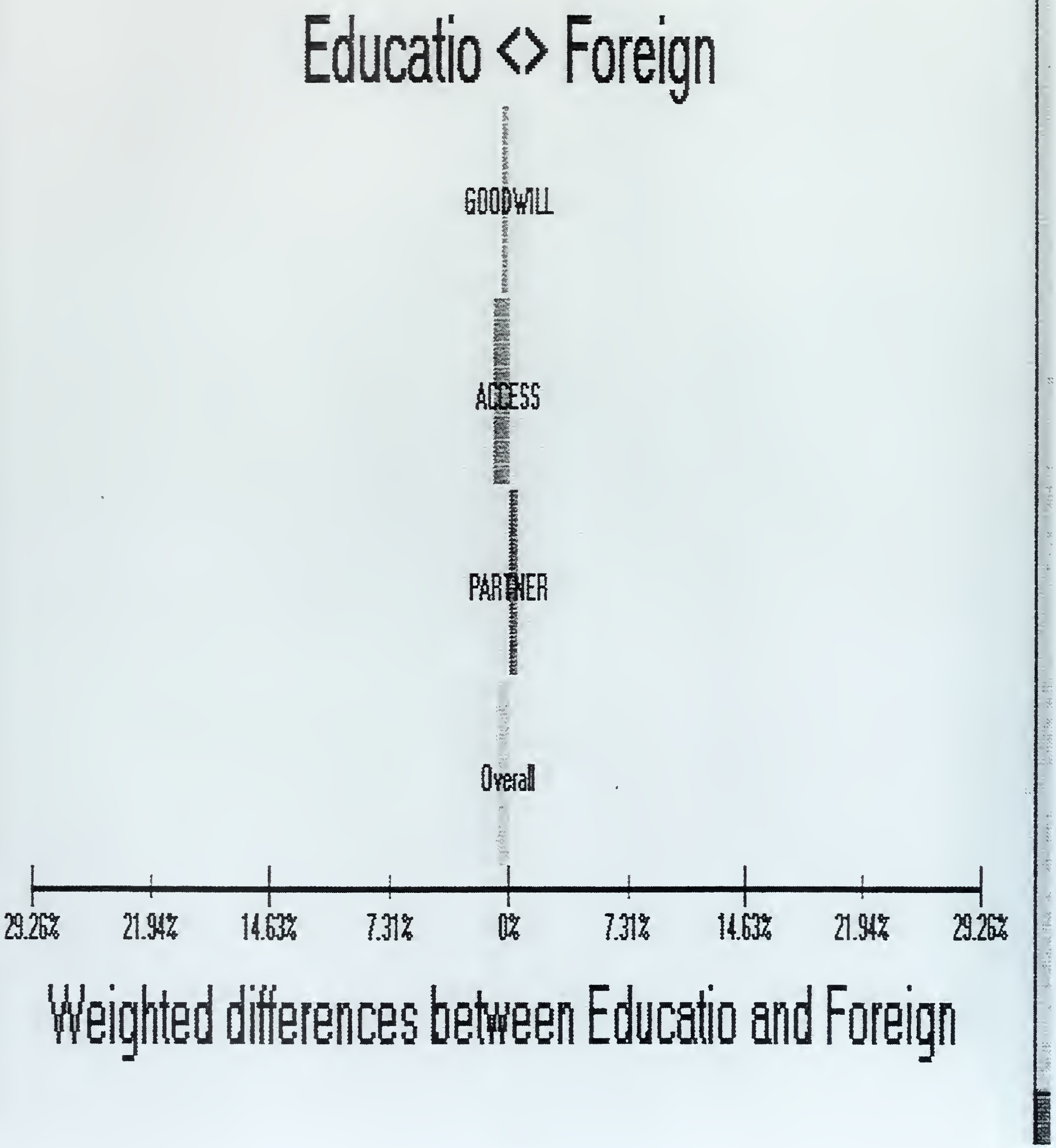
Differences Sensitivity w.r.t. GOAL for nodes below GOAL



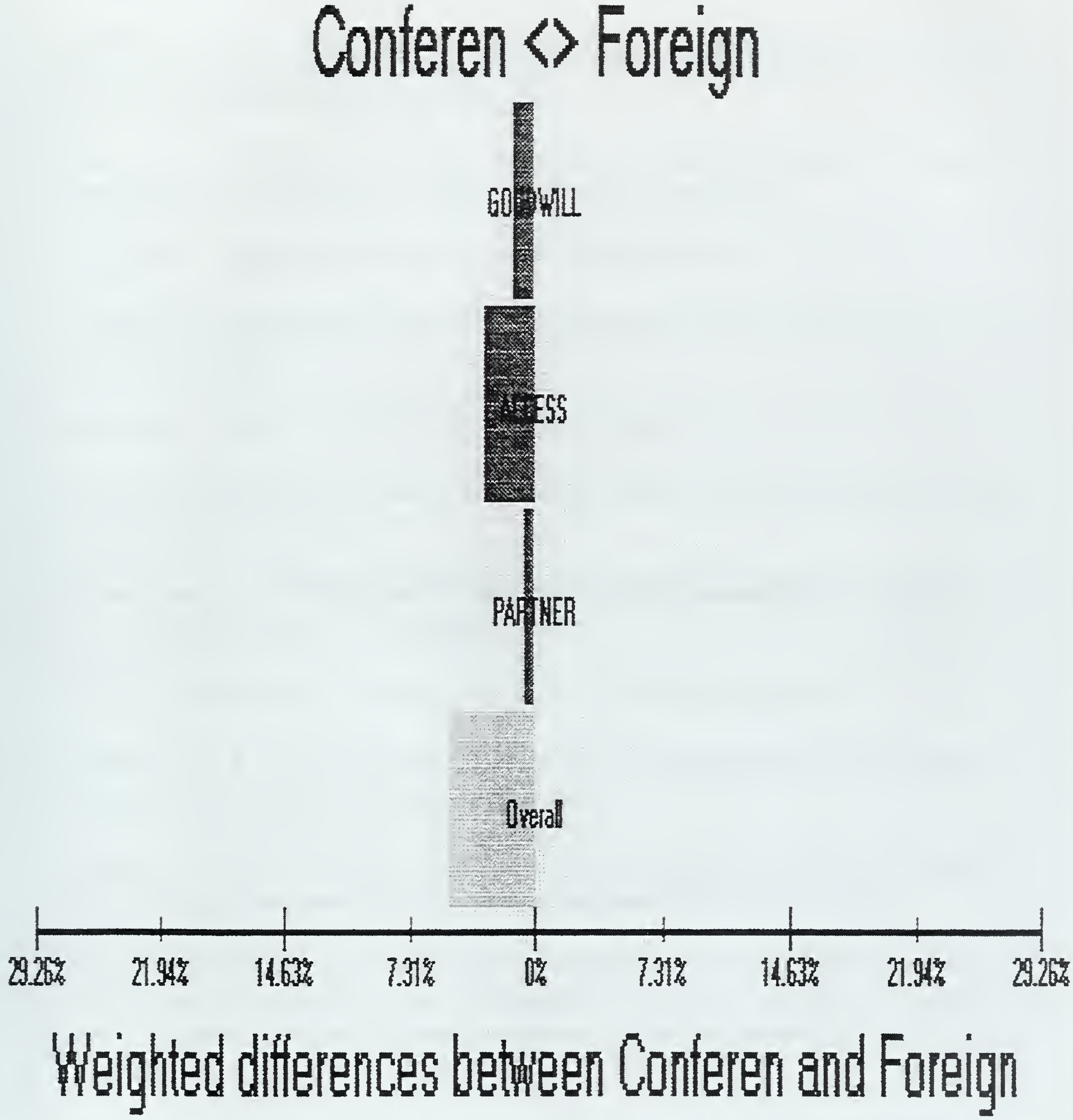
Differences Sensitivity w.r.t. GOAL for nodes below GOAL



Differences Sensitivity w.r.t. GOAL for nodes below GOAL



Differences Sensitivity w.r.t. GOAL for nodes below GOAL



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